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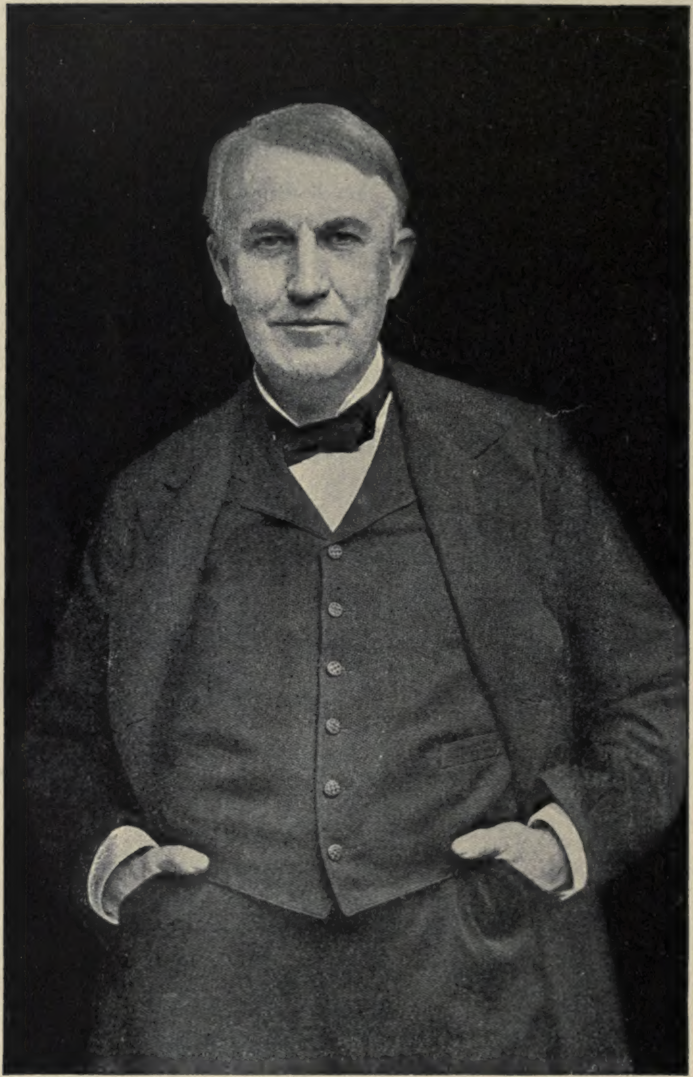

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Inventor of Telegraphic Appliances, Phonograph, Incandescent Lamp, and Many Other Electrical Devices

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Cyclopedia
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Applied Electricity

A General Reference Work
ON DYNAMO-ELECTRIC MACHINERY, GENERATORS, MOTORS, STORAGE
BATTERIES, ELECTRIC WIRING, ELECTRICAL MEASUREMENTS,
ELECTRIC LIGHTING, ELECTRIC RAILWAYS, POWER STATIONS,
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Illustrated with over Two Thousand Engravings

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Authors and Collaborators

FRANCIS B. CROCKER, M. E., Ph. D.

Head of Department of Electrical Engineering, Columbia University
Past-President, American Institute of Electrical Engineers

❧

WILLIAM ESTY, S. B., M. A.

Head of Department of Electrical Engineering, Lehigh University
Joint Author of "The Elements of Electrical Engineering"

❧

JAMES R. CRAVATH

Associate Editor, *Electrical World*

❧

GEORGE C. SHAAD, E. E.

Head of Department of Electrical Engineering, University of Kansas

❧

ROBERT ANDREWS MILLIKAN, Ph. D.

Associate Professor of Physics, University of Chicago

❧

KEMPSTER B. MILLER, M. E.

Consulting Engineer and Telephone Expert
Author of "American Telephone Practice"

❧

LOUIS DERR, S. B., M. A.

Associate Professor of Physics, Massachusetts Institute of Technology

❧

WILLIAM C. BOYRER, M. E., M. M. E.

Formerly Division Engineer, New York & New Jersey Telephone Co.

❧

H. C. CUSHING, Jr.

Consulting Electrical Engineer
Author of "Standard Wiring for Electric Light and Power"

❧

DUGALD C. JACKSON, C. E.

Head of Department of Electrical Engineering, Massachusetts Institute of Technology

SCHOOL OF PRACTICAL SCIENCE TORONTO

Authors and Collaborators—Continued

CHARLES E. KNOX, E. E.

Consulting Electrical Engineer
American Institute of Electrical Engineers

◆

JOHN E. SNOW, A. M., M. S., E. E.

Associate Professor of Electrical Engineering, Armour Institute of Technology
American Institute of Electrical Engineers

◆

SAMUEL G. McMEEN

Consulting Engineer and Telephone Expert

◆

JOHN C. SHERMAN, S. B.

Formerly with the Westinghouse Electric & Manufacturing Co.

◆

DARWIN S. HATCH, B. S.

Assistant Editor, Textbook Department, American School of Correspondence

◆

FRITZ LUBBERGER, E. E.

Chief Engineer, Automatic Electric Co.
Western Society of Engineers

◆

WILLIAM H. FREEDMAN, C. E., E. E., M. S.

Head of Department of Electrical Engineering, University of Vermont

◆

JOHN LORD BACON

Consulting Engineer
Formerly Instructor in Forge Work, Lewis Institute, and Instructor in Shop Work, University of Chicago

◆

GEORGE R. METCALFE, M. E.

Head of Technical Publication Department, Westinghouse Electric & Manufacturing Co.
Formerly Technical Editor, *Street-Railway Review*

◆

ERNEST L WALLACE, B. S.

Instructor in Electrical Engineering, American School of Correspondence
American Institute of Electrical Engineers

◆

GEORGE W. PATTERSON, S. B., Ph. D.

Head of Department of Electrical Engineering, University of Michigan

Authors and Collaborators—Continued

CHARLES THOM

Chief, Quadruplex Department, Western Union Telegraph Co.

❧

JAMES DIXON, E. E.

American Institute of Electrical Engineers

❧

R. F. SCHUCHARDT, B. S.

Testing Engineer, Chicago Edison Co.

❧

A. FREDERICK COLLINS

Author of "Wireless Telegraphy, Its History, Theory, and Practice"

❧

LAWRENCE K. SAGER, S. B., M. P. L.

Patent Attorney and Electrical Expert
Formerly Assistant Examiner, U. S. Patent Office

❧

EDWARD B. WAITE

Head of Instruction Department, American School of Correspondence
American Society of Mechanical Engineers

❧

PERCY H. THOMAS, S. B.

Of Thomas & Neall, Electrical Engineers, New York City
Formerly Chief Electrician, Cooper Hewitt Electric Co.

❧

ALTON D. ADAMS

Consulting Engineer and Expert on Hydro-Electric Power Development

❧

GLENN M. HOBBS, Ph. D.

Secretary, American School of Correspondence
Formerly Instructor in Physics, University of Chicago
American Physical Society

❧

CHARLES DAY

With Dodge & Day, Engineers, Philadelphia
American Institute of Electrical Engineers

❧

HARRIS C. TROW, S. B., ***Managing Editor***

Editor-in-Chief of Textbook Department, American School of Correspondence
American Institute of Electrical Engineers

Authorities Consulted

THE editors have freely consulted the standard technical literature of America and Europe in the preparation of these volumes. They desire to express their indebtedness, particularly to the following eminent authorities, whose well-known works should be in the library of every electrician and engineer.

Grateful acknowledgment is here made also for the invaluable co-operation of the foremost engineering firms and manufacturers in making these volumes thoroughly representative of the very best and latest practice in the design, construction, and operation of electrical machinery and instruments; also for the valuable drawings, data, suggestions, criticisms, and other courtesies.

FRANCIS B. CROCKER, M. E., Ph. D.

Head of Department of Electrical Engineering, Columbia University; Past-President, American Institute of Electrical Engineers

Author of "Electric Lighting;" Joint Author of "Management of Electrical Machinery"

◆

SCHUYLER S. WHEELER, D. Sc.

President, American Institute of Electrical Engineers; Member, American Societies of Civil and Mechanical Engineers

Joint Author of "Management of Electrical Machinery"

◆

ALFRED E. WIENER, E. E., M. E.

Member, American Institute of Electrical Engineers

Author of "Practical Calculation of Dynamo-Electric Machines"

◆

WILLIAM S. FRANKLIN, M. S., D. Sc.

Professor of Physics, Lehigh University

Joint Author of "The Elements of Electrical Engineering," "The Elements of Alternating Currents"

◆

WILLIAM ESTY, S. B., M. A.

Head of Department of Electrical Engineering, Lehigh University

Joint Author of "The Elements of Electrical Engineering"

◆

R. B. WILLIAMSON

Joint Author of "The Elements of Alternating Currents"

◆

HORATIO A. FOSTER

Member of American Institute of Electrical Engineers; Member of American Society of Mechanical Engineers; Consulting Engineer

Author of "Electrical Engineer's Pocket-book"

J. FISHER-HINNEN

Late Chief of the Drawing Department at the Oerlikon Works
Author of "Continuous-Current Dynamos"

❧

WILLIAM L. HOOPER, Ph. D.

Head of Department of Electrical Engineering, Tufts College
Joint Author of "Electrical Problems for Engineering Students"

❧

ROBERT ANDREWS MILLIKAN, Ph. D.

Associate Professor of Physics, University of Chicago
Joint Author of "A First Course in Physics," etc.

❧

DUGALD C. JACKSON, C. E.

Head of Department of Electrical Engineering, Massachusetts Institute of Technology; Member, American Society of Mechanical Engineers, American Institute of Electrical Engineers, etc.

Author of "A Textbook on Electromagnetism and the Construction of Dynamos;" Joint Author of "Alternating Currents and Alternating-Current Machinery"

❧

JOHN PRICE JACKSON, M. E.

Professor of Electrical Engineering, Pennsylvania State College; Member, American Institute of Electrical Engineers, etc.

Joint Author of "Alternating Currents and Alternating-Current Machinery"

❧

WILLIAM KENT, M. E.

Consulting Engineer; Member, American Institute of Mining Engineers, American Society of Mechanical Engineers, etc.

Author of "The Mechanical Engineer's Pocket-book;" "Strength of Materials," "Steam Boiler Economy," etc.

❧

LAMAR LYNDON, B. E., M. E.

Consulting Electrical Engineer; Associate Member of American Institute of Electrical Engineers; Member, American Electro-Chemical Society

Author of "Storage Battery Engineering"

❧

EDWIN J. HOUSTON, Ph. D.

Professor of Physics, Franklin Institute, Pennsylvania; Joint Inventor of Thomson-Houston System of Arc Lighting; Electrical Expert and Consulting Engineer

Joint Author of "Alternating Currents," "Arc Lighting," "Electric Heating," "Electric Motors," "Electric Railways," "Incandescent Lighting," etc.

❧

ARTHUR E. KENNELY, D. Sc.

Joint Author of "Alternating Currents," "Arc Lighting," "Electric Heating," "Electric Motors," "Electric Railways," "Incandescent Lighting," etc.

Authorities Consulted—Continued

SILVANUS P. THOMPSON, D. Sc., B. A., F. R. S., F. R. A. S.

Principal and Professor of Physics in the City and Guilds of London Technical College; Past-President, Institution of Electrical Engineers

Author of "Electricity and Magnetism," "Dynamo-Electric Machinery," "Polyphase Electric Currents and Alternate-Current Motors," "The Electromagnet," etc.

⁂

KEMPSTER B. MILLER, M. E.

Consulting Engineer and Telephone Expert

Author of "American Telephone Practice"

⁂

MAURICE A. OUDIN, M. S.

Member, American Institute of Electrical Engineers

Author of "Standard Polyphase Apparatus and Systems"

⁂

FREDERICK BEDELL, Ph. D.

Professor of Applied Electricity, Cornell University

Author of "The Principles of the Transformer;" Joint Author of "Alternating Currents"

⁂

H. F. PARSHALL

Member of American Institute of Electrical Engineers, Institution of Electrical Engineers, American Society of Mechanical Engineers, etc.

Joint Author of "Armature Windings of Electric Machines"

⁂

H. M. HOBART, S. B.

Joint Author of "Armature Windings of Electric Machines"

⁂

J. A. FLEMING, M. A., D. Sc. (Lond.), F. R. S.

Professor of Electrical Engineering in University College, London; Late Fellow and Scholar of St. John's College, Cambridge; Fellow of University College, London; Member, Institution of Electrical Engineers; Member of the Physical Society of London; Member of the Royal Institution of Great Britain, etc., etc.

Author of "The Alternate-Current Transformer," etc.

⁂

LOUIS BELL, Ph. D.

Member of American Institute of Electrical Engineers, etc.

Author of "Electric Power Transmission," "Power Distribution for Electric Railways," "The Art of Illumination," etc.

⁂

CHARLES PROTEUS STEINMETZ

Consulting Engineer, with the General Electric Co.; Professor of Electrical Engineering, Union College

Author of "The Theory and Calculation of Alternating-Current Phenomena," "Theoretical Elements of Electrical Engineering," etc.

⁂

A. FREDERICK COLLINS

Author of "Wireless Telegraphy, Its History, Theory and Practice," "Manual of Wireless Telegraphy," etc.

Authorities Consulted—Continued

E. B. RAYMOND

Testing Department, General Electric Co.
Author of "Alternating-Current Engineering"

❧

J. J. THOMSON, D. Sc., LL. D., Ph. D., F. R. S.

Fellow of Trinity College, Cambridge University; Cavendish Professor of Experimental Physics, Cambridge University
Author of "The Conduction of Electricity through Gases," "Electricity and Matter," etc.

❧

GEORGE T. HANCHETT, S. B.

Member, American Institute of Electrical Engineers
Author of "Modern Electric-Railway Motors"

❧

F. A. C. PERRINE, A. M., D. Sc.

Consulting Engineer; Formerly President, Stanley Electric Manufacturing Company; Formerly Manager, Insulated Wire Department, John A. Roebling's Sons Company; Formerly Professor of Electrical Engineering, Leland Stanford Jr. University
Author of "Conductors for Electrical Distribution"

❧

WILLIAM MAVER, Jr.

Ex-Electrician Baltimore and Ohio Telegraph Company; Member of the American Institute of Electrical Engineers
Author of "Wireless Telegraphy;" "American Telegraphy and Encyclopedia of the Telegraph"

❧

AUGUSTUS TREADWELL, Jr., E. E.

Associate Member, American Institute of Electrical Engineers
Author of "The Storage Battery: A Practical Treatise on the Construction, Theory, and Use of Secondary Batteries"

❧

SAMUEL SHELDON, A. M., Ph. D.

Professor of Physics and Electrical Engineering, Polytechnic Institute of Brooklyn; Member, American Institute of Electrical Engineers, etc.
Joint Author of "Dynamo-Electric Machinery," "Alternating-Current Machines"

❧

HOBART MASON, B. S., E. E.

Assistant in Electrical Engineering, Polytechnic Institute of Brooklyn; Associate Member, American Institute of Electrical Engineers
Joint Author of "Dynamo-Electric Machinery," "Alternating-Current Machines"

❧

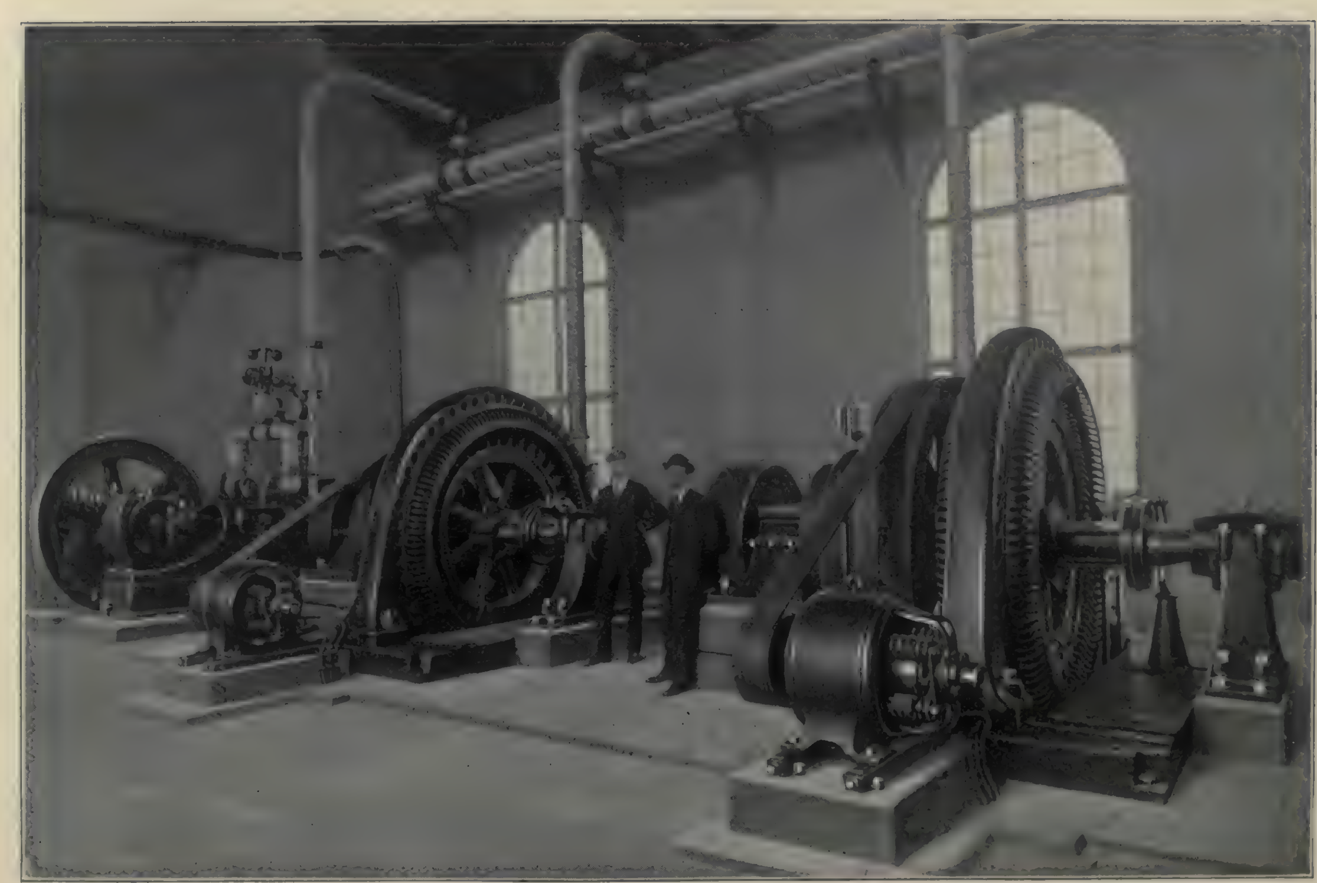
H. M. HOBART, B. Sc.

Member, Institution of Civil Engineers, Institution of Electrical Engineers, American Institute of Electrical Engineers
Joint Author of "Armature Construction"

❧

SYDNEY W. ASHE, B. S.

Department of Electrical Engineering, Polytechnic Institute of Brooklyn; Late Instructor in Electric Traction for the Brooklyn Rapid Transit Co.; Associate Member, American Institute of Electrical Engineers
Joint Author of "Electric Railways, Theoretically and Practically Treated"



POWER HOUSE INSTALLATION OF THE HOCKING VALLEY RAILWAY COMPANY'S SHOPS AT LOGAN, OHIO
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Foreword

IN view of the great need for a more scientific knowledge of electricity by thousands of practical men of limited technical education, an attempt has been made in the following pages to give a presentation of the subject which will be easily understood by such men, and at the same time cover all essential principles and methods. The principles usually deduced by higher mathematics are here made clear by careful explanation and a large number of diagrams drawn especially to supplement and elucidate the text. Numerous engravings exemplify modern practice, and form a pictorial index to the latest and best methods of applying electricity to lighting, railways, power transmission, the driving of machine tools, etc.

¶ The Cyclopedia of Applied Electricity is based upon the method which the American School of Correspondence has developed and successfully used for many years in teaching practical electricians the scientific principles underlying their work. It is a compilation of representative Instruction Papers of the School, and forms a simple, practical, concise, and convenient reference work for the shop, the library, the school, and the home.

¶ The success which the American School of Correspondence has attained in teaching thousands of electricians, is in itself the best possible guarantee for the present work. Therefore, while these volumes are a marked innovation in technical literature—representing as they do the best ideas and methods of a large number of different authors, each an acknowledged authority in his work—they are by no means an experiment, but are in fact based on what has proved itself to be the most successful method yet devised for the education of the busy working man.

¶ Among the sections of especial timeliness are those on Alternating-Current Machinery, Storage Batteries, Electric Wiring, Lighting, etc. In these pages the authors have succeeded in presenting the subjects in such manner as to overcome the hitherto insurmountable obstacle—higher mathematics. The rules and formulæ are presented in a very simple manner, and special effort has been made to illustrate every principle by diagrams, curves, and practical examples.

¶ Numerous examples for practice are inserted at intervals; these, with the test questions, help the reader to fix in mind the essential points, thus combining the advantages of a textbook with those of a reference work.

¶ Grateful acknowledgment is due to the corps of authors and collaborators who have prepared the many sections of this work. The hearty co-operation of these men—engineers of wide practical experience, and teachers of acknowledged ability—has alone made these volumes possible.

¶ The Cyclopedia is published in the belief that it will meet a real need among designers, constructors, and operators of electrical machinery. That it may save many weary hours of search among the scattered textbooks and reference works of the day—books which, being intended largely for college-trained men, are necessarily far from meeting the needs of the average practical man—is the hope of the compilers and publishers.

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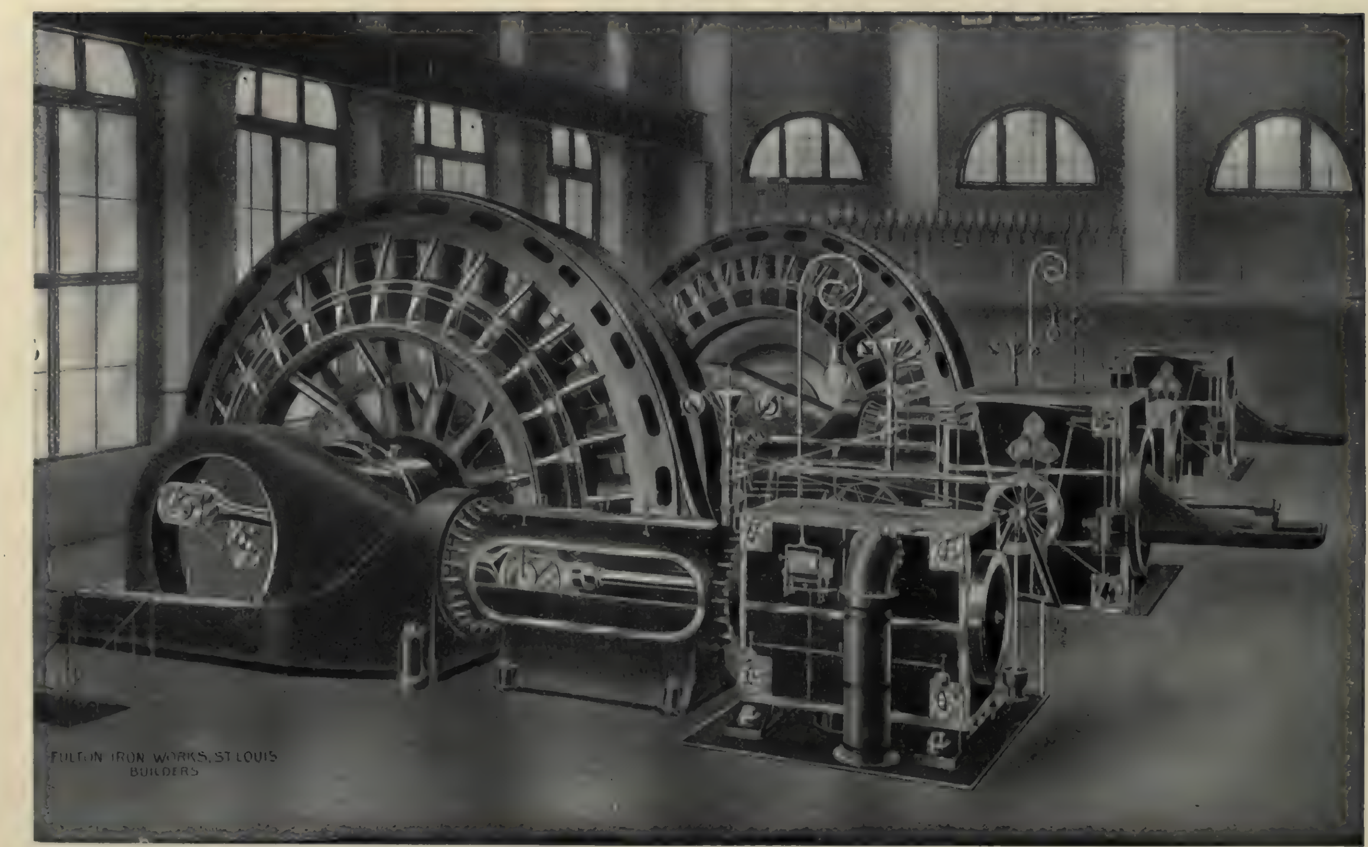

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ELECTRICAL MEASUREMENTS

PART I—ELEMENTARY

SYSTEMS OF UNITS

Physical quantities are measured in terms of quantities called units. These units, as a rule, are related to one another and form systems; as, for example, the *British* system and the *C. G. S.* system.

Fundamental Units. The arbitrarily chosen units of a system are called *fundamental* in distinction to the related units depending on them, which are called *derived* units. The C. G. S. system, universally used in electrical measurements, takes its name from three of its fundamental units—the *centimeter*, the *gram*, and the *second of mean solar time.* Besides the three units from which it takes its name, the C. G. S. system includes other fundamental units; for example, the *degree centigrade*, the *calorie*, and the *unit magnetic pole.* Whenever the arbitrary choice of a property of a substance enters into the choice of a unit, the unit itself becomes fundamental. Thus the calorie depends on the thermal capacity of water; the unit magnetic pole depends on the magnetic property of air, etc.

Derived Units. Geometrical units, such as area and volume, are derived from the unit of length. That is, areas are measured in square centimeters, and volumes in cubic centimeters, involving units of the second and third degree with reference to the unit of length. We say that an area has a dimension of 2 and a volume of 3 in terms of a length. Put algebraically, an area may be expressed as L^2, and a volume as L^3 in terms of a length L. In mechanics we use derived units depending on length L, mass M, and time T. Thus velocity, which may be measured by the ratio of length and time, has as dimensions LT^{-1}, and acceleration LT^{-2}. Force is more complicated and may be defined in terms of the acceleration of a mass. The dimensions of force are then LMT^{-2}. The C. G. S. unit of force is called the *dyne*. Work and energy may be measured in terms of force exerted through space, and the unit, equal to one dyne acting through one

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centimeter, is called the *erg*. The dimensions of the erg are $L^2 M T^{-2}$. In the same way power (time rate of doing work) may be expressed in ergs per second. This unit of power is so small that for practical purposes we use the *watt* which is 10,000,000 ergs per second. Even the watt is small and so we frequently use the *kilowatt* (one thousand watts) for measurement of power. As we shall see later, the watt is used also for the measurement of power for electric circuits. Besides the C. G. S. units we use many units which are multiples or submultiples and so are related. For example, we use the meter (100 centimeters) and the kilometer (100,000 centimeters) and the millimeter (0.1 centimeter). Evidently the meter was intended to be the fundamental unit, the centimeter and the millimeter submultiples, and the kilometer a multiple; but in the C. G. S. system the meter becomes a multiple of the fundamental unit.

In electrical measurements the unit of resistance—the *ohm*—is practically taken as 1,000,000,000 C. G. S. units; the unit of electromotive force (e. m. f.)—the *volt*—is taken as 100,000,000 C. G. S. units; and the unit of current—the *ampere*—is taken as 0.1 C. G. S. unit. These units were originally recommended by a committee of the British Association for the advancement of science in 1873, and were internationally adopted at Paris in 1881. The watt is the practical unit of power and is equal to an e. m. f. of one volt multiplied by a current of one ampere. If the current is constant the product of current and e. m. f. gives the power. If the current is not constant, the average product of current and e. m. f. gives the average power. As we shall see later in the case of alternating currents, the readings of alternating-current voltmeters and ammeters cannot be multiplied together to get the power; but an instrument called a *wattmeter* must be used. The wattmeter gives the correct result. The watt is 10,000,000, *i. e.*, 10^7 C. G. S. units.

The unit of charge (or quantity)—the *coulomb*—is the quantity of electricity equal to a flow of one ampere for one second. The coulomb is 0.1 C. G. S. unit. The *farad* is the unit of capacity. A condenser has one farad capacity if it can store one coulomb with a potential difference of one volt at its terminals. Potential difference, like e. m. f., is practically measured in volts. At higher potential differences a condenser takes a proportionately higher charge. The farad is a very large capacity and condensers are practically rated in microfarads, *i. e.*, in millionths of a farad. The *henry* is the unit of inductance. When a current is started in a coil of wire a magnetic field is produced. This requires more e. m. f. than to maintain the current when once started. If the coil requires one volt more to increase the current at the rate of one ampere per second than to maintain it, we say the inductance of the coil is one henry. The henry is 1,000,000,000, *i. e.*, 10^9 C. G. S. units. These practical units are all related, as is seen above, to the C. G. S. units by factors, of powers of 10. There are other units in the electro-magnetic system for which the reader is referred to more advanced works.

Relation of C. G. S. to British Units. To reduce British to C. G. S. units and *vice versâ*, we make use of the relations between them. One inch equals 2.54 centimeters; one pound mass equals 453.59 grams mass; and a like relation between pounds weight (force) and grams weight. The second of mean solar time is the same in both systems. It should be kept in mind that for equal quantities the number of units is inversely proportional to the size of the unit.

ELECTRICAL MEASURING APPARATUS

Galvanometers. In the year 1819 Oersted discovered that a current flowing through a conductor produced an effect on a magnet. This effect is now explained by saying that lines of force surround the conductor, and that the north pole of the magnet tends to move along the lines of force in one direction and the south pole in the opposite direction. In other words the magnet, if free to move, tends to take a direction across the conductor. In the case of a long, straight wire the lines of force are circumferences of circles with the conductor at the center. The force on the magnet pole in this case falls off in proportion to the increase in the distance from the center of the conductor; *i. e.*, the force is inversely proportional to the distance. If the magnet is already in a magnetic field, such as that of the earth for instance, a current in a north and south wire above or below the magnet, tends to turn the magnet away from the

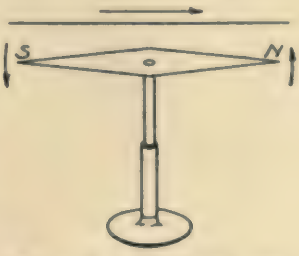


Fig. 1. Oersted's Experiment.

magnetic north and south, the tangent of the angle through which it turns being proportional to the current, Fig. 1. The effect of a single wire is small unless the current is very large.

Tangent Galvanometer. If the conductor is wound in a coil whose plane is north and south and vertical, the effect on a magnet at the center is multiplied many times, Fig. 2. Such an instrument is called a *tangent galvanometer.* If the thumb of the right hand is placed along the outside of the conductor pointing in the direction of the current, the fingers of the hand may be curled around the conductor and will point in the direction toward which the north pole of the magnet will be urged by the field produced. A similar arrangement of the left hand will indicate the direction in which the south pole will be urged.

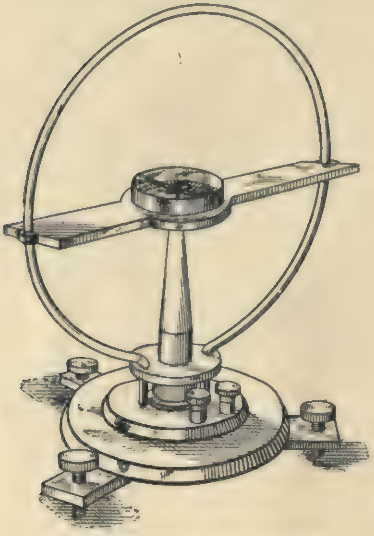


Fig. 2. Tangent Galvanometer.

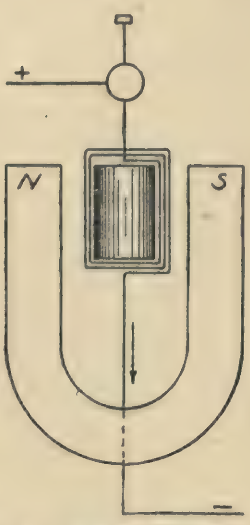


Fig. 3. Diagram of D'Arsonval Galvanometer.

D'Arsonval Galvanometer. If the magnet is fixed and the coil free to turn, the latter will turn in the reverse direction. If the magnet is of the horse-shoe type with the coil of wire between the poles a similar rule will determine the direction of motion. Galvanometers of the moving coil type were invented by D'Arsonval and Deprez, and are usually called *D'Arsonval galvanometers,* Fig. 3.

Astatic Galvanometer. An improvement may be made in the tangent galvanometer, if greater sensitiveness is desired, by mounting on the same support two magnets of nearly but not quite equal strength, care being taken to turn the poles in exactly opposite directions. This is very important. One magnet is placed at the center of the coil through which the current is sent and the other magnet is above or below the coil and influenced relatively little by the current, Fig. 4. The directive action of the earth's magnetic field is little on such a system—called *astatic*—and a small current consequently turns the system more easily from the magnetic meridian. A similar effect is produced if part of the coil is about one magnet and the rest, with reversed direction of the current, about the other magnet. Another way to produce an equivalent effect on a single, suspended magnet is to mount a powerful control magnet near by (above, below, or behind) so as to reduce to a very small amount the magnetic field due to the earth and the control magnet at the center of the coil.

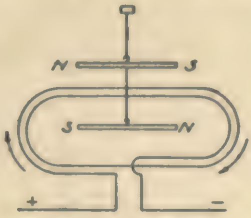


Fig. 4. Astatic System.

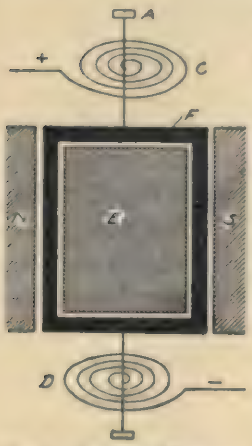


Fig. 5. Section of Suspension of Portable Galvanometer.

An extremely sensitive galvanometer may be made by combining the control magnet with the astatic system of magnets. The magnet (or system of magnets) of tangent and astatic galvanometers is suspended generally either by a fine silk or quartz fiber. The current is led into and out of the coil of the D'Arsonval galvanometer through two wires, both above in the bifilar suspension, one above and one below in the unifilar suspension.

Less sensitive galvanometers may have their moving parts mounted on pivots or other bearings, and in such galvanometers of the D'Arsonval type the current is brought in and out through spiral springs which tend to hold the coil in its zero position, Fig. 5. Galvanometers of this type are used for ammeters—to measure amperes of current; or for voltmeters — to measure e. m. f. in volts. Such instruments are provided with some damping arrangement so that they come to rest quickly. The deflection of such galvanometers is indicated by a pointer moving on a scale. If the poles of the magnet are properly shaped the deflection may be made proportional to the current passing.

Mirror Galvanometers. Very sensitive galvanometers must be made with moving parts of little weight. It is, however, very desirable that the pointer be very long so that a large number of scale parts may correspond to small deflections. This may be accomplished by using a pencil of light rays for a pointer, as shown in Fig. 6, which illustrates the lamp-and-scale method, in which a lamp is placed behind a slit in a screen on which the scale is mounted. A concave mirror carried on the moving part of the galvanometer focuses an image of the slit at the reference point of the scale (usually the middle). When current passes, the mirror is deflected, thus deflecting the rays of light to another part of the scale. If the mirror turns through 1°, the image is deflected 2°. In place of a slit an opening of another form with cross wires may be substituted. Also if desired the lamp may be mounted at the side, and its light reflected by another mirror to the mirror on the galvanometer. In this last case it is more convenient to have the scale printed on a strip of translucent ground glass or paper, and to view the image through the glass or paper. If a telescope is substituted for the lamp, an image of the reference point of the scale may be made to coincide with the cross wire of the telescope

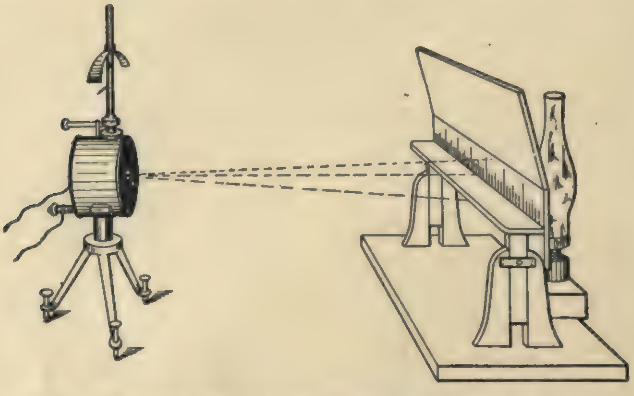


Fig. 6. Thomson Mirror Galvanometer with Lamp and Scale.

when no current is passing, and other parts of the scale will take the place of the reference point when a deflection is produced, Fig. 7. In this case a plane mirror may take the place of the concave. The telescope-and-scale method is more satisfactory for very sensitive galvanometers than the lamp-and-scale method, though the latter, usually used in a darkened room, is easier on the eyes unless an excellent galvanometer mirror and telescope are used.

Choice of Galvanometers. In choosing a galvanometer for use, it is desirable that the instrument should not be too sensitive for the experiment. As a rule the D'Arsonval galvanometer is the most satisfactory galvanometer for general use, as it is not much affected by changes in the magnetic field, even if of as great amount as produced by dynamo-electric machinery or moving of masses of iron in the neighborhood. The astatic galvanometer is, however, as a rule, far more sensitive and for certain purposes must be used.

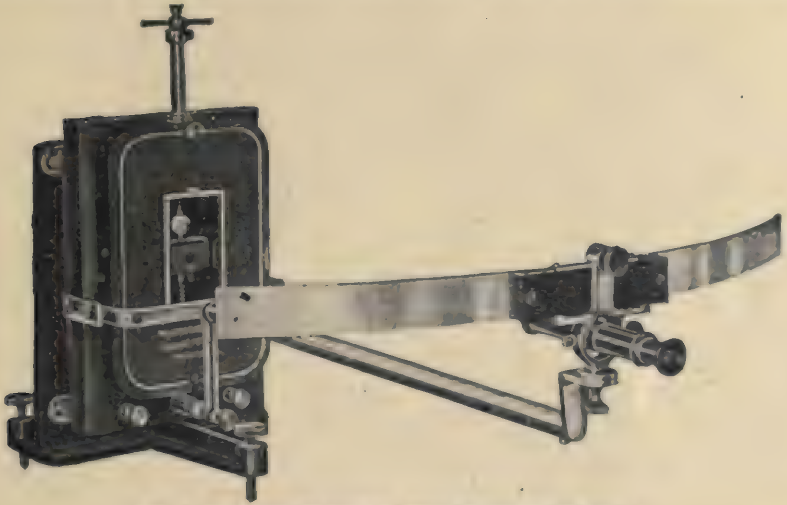


Fig. 7. Ballistic D'Arsonval with Telescope and Scale.

Use of the Control Magnet. In using astatic or other galvanometers with moving magnets, the use of the control magnet is sometimes very puzzling to beginners. The galvanometer should be set up with its coils in a north and south plane. The mirror then faces to the west (or east sometimes). The control magnet is then placed in position as far away as its support will allow and turned with its north pole to the north. The magnets and the mirror of the galvanometer, as a rule, are somewhat deflected because of the presence of the control magnet. If the latter is slightly turned in one direction, the mirror should turn in the opposite direction. As the control magnet is brought nearer, the period of swing of the mirror should increase, and the sensibility should increase in a greater proportion (as the square). If by chance the control magnet is with its south pole to the north, the mirror will turn in the same direction as the control magnet is turned, and the period of swing will decrease as the control magnet is brought nearer. Control magnets as a rule have the north pole marked in some way, so that there is no need for any mistake. When the control magnet is brought so close that the effect of the earth's field is overcome, the magnets and mirror of the galvanometer will try to turn half way around, thus turning the back of the mirror to the observer, if the construction of the galvanometer will allow. As a rule it does not pay to increase the sensitiveness of the galvanometer to the highest possible limit, as the zero reading will become very easily influenced by slight magnetic changes due to movement of small masses of iron, or the currents in neighboring conductors, or even the variation in the magnetic field due to a cloud cutting the sunlight off from the walls of a red brick laboratory, small as such an effect must be. If the galvanometer is of the astatic type, it is presupposed in the above that the support for the control magnet is arranged to weaken the field of the stronger magnet of the astatic pair more than it does the field of the weaker magnet. In some poorly adjusted galvanometers, the control magnet may produce the contrary result, and it may be necessary to make appropriate allowance. If the magnets of the astatic galvanometer take an east and west position before the control magnet is put on, it is evident that the magnets of the astatic pair are not exactly in opposite directions and that the result is a magnetic system having its effective or resultant north pole about half way between the north poles, and its resultant south pole about half way between the south poles of the two magnets. The line joining these resultant poles lies in the magnetic meridian and the magnets of the astatic pair lie nearly east and west. To correct this error in adjustment is a very delicate matter and should not be attempted by the novice.

Ballistic Galvanometer. When a charge condenser is discharged through a circuit containing a galvanometer, the galvanometer deflects. The period of swing should be long enough for practically the whole charge to pass during the early part of the swing. If the galvanometer has a short period, the return swing may begin before the discharge is complete. It may be assumed that the first deflection is a measure of the quantity discharged; but it is evident that this is an error if the discharge is slow in comparison with the time occupied by the deflection. To be on the safe side the period of swing should be large. Galvanometers which are suitable for measuring discharges are called *ballistic.* Depending on circumstances, their period may be between, say, five and twenty seconds for the complete swing. The D'Arsonval galvanometer may be made with high enough period and sensibility to give satisfaction as a ballistic instrument; but for extreme sensibility an instrument of the astatic type is more generally used. The D'Arsonval galvanometer is more nearly free from the drift of the reference point, which is due mostly to varying magnetic field and somewhat to elastic fatigue or subpermanent set in the suspension. Freedom from drift is very important, as the deflection is uncertain in proportion as the reference point is in doubt.

Damping of Vibrations. The motion of the moving system of a galvanometer may be impeded by damping. This may be accomplished by mounting vanes on the system so that the air in an enclosed chamber impedes the motion, or by electromagnetic damping produced by eddy currents induced in metal moving in a strong magnetic field. In D'Arsonval galvanometers if the coil is wound on a metal frame, currents will be induced in the frame while the coil is in motion. Such damping ensures a speedy coming to rest after a deflection and is very helpful, especially in ballistic galvanometers where certainty of zero is important. It is evident that any damping reduces the sensibility of a galvanometer. Some galvanometers are provided with so much damping that on the return swing the system does not swing past the zero or reference point. Galvanometers without a period of complete vibration are said to be *aperiodic* (the *a* denoting without). As a rule galvanometers have a complete period, that is, they are damped less than the aperiodic galvanometer. The effect of damping is to shorten the time and amplitude of the outward part of the swing (though it lengthens the complete period), and to this extent damping is objectionable. There are, however, counter-balancing advantages and so for most purposes some damping is considered wise.

Plunger Type Instruments If in place of the magnet of a galvanometer, some soft iron is substituted in such a position that the action of the current is to magnetize the soft iron and to draw it into a stronger part of the magnetic field, we have a *current indicator* of the plunger type. The coil frequently takes the form of a solenoid and the soft iron that of a rod which is drawn by the action of the current into the solenoid. The restraining force may be gravitational or that of a spring. Such an instrument is shown in Fig. 8. It is evident that the direction of the deflection does not depend on the direction of the current. In fact, plunger type instruments may be used to measure alternating currents. There are many possible variations of this type of instrument. As the iron has a certain amount of residual magnetization, the deflection with smaller following large currents is more than would have been produced by the same current following a smaller one. For this reason the plunger type of instrument is less reliable than the usual types of galvanometers. The scale is usually of unequal divisions as the pull increases more rapidly than the current.

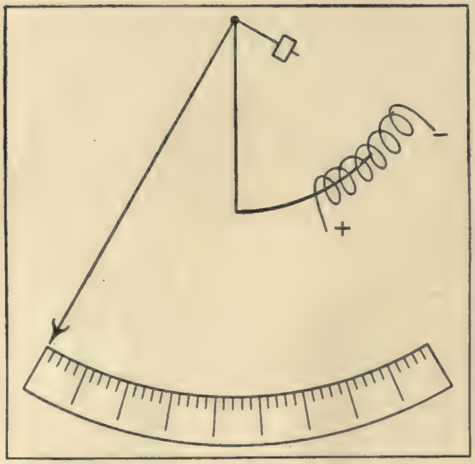


Fig. 8. Diagram of Plunger Instrument.

Electrodynamometers. If the magnet of a galvanometer is replaced by a coil through which the current passes in series with the other coil, we have what is known as an *electrodynamometer*. As in the case of the plunger type instruments, the electrodynamometer deflects in the same direction for all currents unless disturbed by being placed in a magnetic field of outside origin. It is desirable to set up an electrodynamometer with the moving coil (or coils, if more than one) with its axis (or their axes) along the magnetic meridian.

The disturbing effect of a permanent field is negligible when the electrodynamometer is used to measure alternating currents. For direct currents, the action of the outside field is eliminated by reversing the connections. The deflection is approximately proportional to the square of the current. For the best types of electrodynamometers the suspended coil is brought back to its zero position by twisting a torsion head which operates through a spiral spring on the suspended coil. The current in this type of instrument is proportional to the square root of the reading of the torsion head necessary to restore the moving coil to its zero position. A direct current producing the same deflection as an alternating current is said to be the effective value of the alternating current. Fig. 9 illustrates the usual type of electrodynamometer. Fig. 10 illustrates another form invented by Lord Kelvin and called a *Kelvin balance*. The figure shows the connections viewed from the back of the balance. The fixed coil is subdivided into four parts *B*, and the moving coil into two parts *A*, placed symmetrically between the parts of *B*. The parts of *A* are supported on opposite arms of a balance and the balance is restored to its zero position by displacing a weight along the beam.

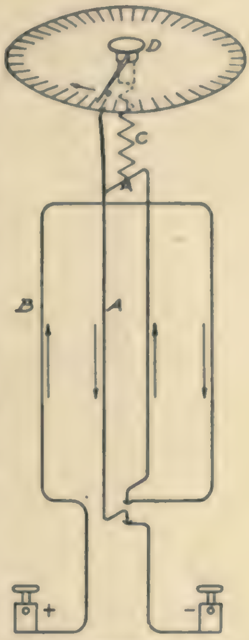


Fig. 9. Electrodynamometer Diagram.

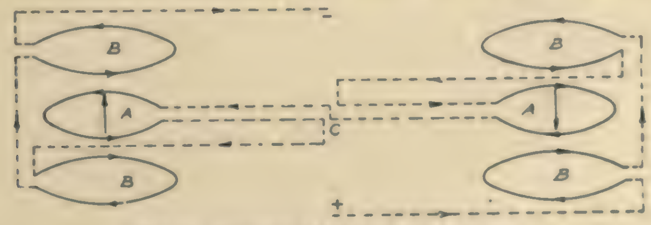


Fig. 10. Diagram of Coils in Kelvin Balance.

The action of the current is thus weighed, and the square of the current is proportional to the distance the weight is moved along the beam. The beam is divided accurately into equal parts and it is possible to obtain the reading with a high degree of accuracy. The current is proportional to the square root of the reading. The effect of dividing the two parts of A is to free the instrument from the disturbing effect of the earth's magnetic field or any other stray field of fairly uniform intensity.

Electrometers. Electrometers depend on the attraction between electrostatic charges of opposite signs. The only electrometer which we shall describe is the *electrostatic voltmeter* which consists of fixed and movable metallic parts of relatively large surface. These surfaces may be plane or curved. The terminals are connected, as a rule, one to the fixed part and the other to the movable part—the vane. These parts take charges proportional to the potential difference between them—e. m. f. applied—and a certain attraction results therefrom. If the vane is allowed to move, the electrostatic capacity of the combination increases somewhat, thus increasing the amount of the charges and the attractive force. If it is desired, the vane may be brought back to its zero position by some counter force. As a rule electrostatic instruments are allowed to deflect and are calibrated by comparison with other forms of voltmeters. More complicated forms of electrostatic instruments may have two sets of fixed surfaces and a movable vane. In some cases a battery of cells of known e. m. f. may be used to charge the fixed surfaces, and the e. m. f. to be measured may be applied between one fixed surface and the vane. Electrostatic voltmeters are generally used to measure high electromotive forces. Fig. 11 shows an electrostatic voltmeter of an old type, which shows

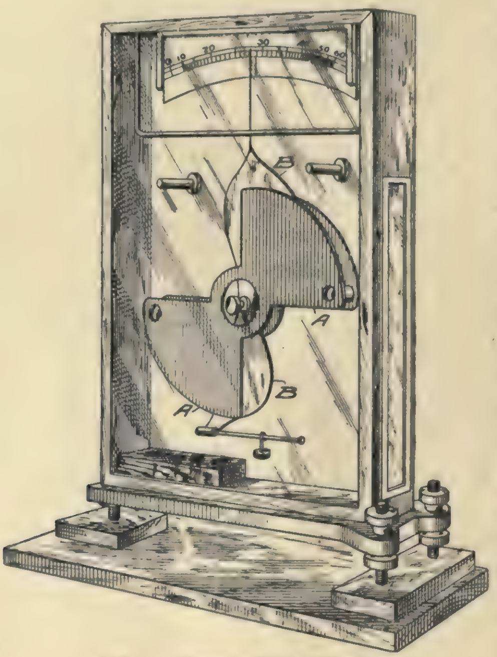


Fig. 11. Electrostatic Voltmeter.

the general scheme more clearly than better and more complicated electrometers.

Hot Wire Instruments. If current passes through a wire, a heating effect results and the wire lengthens because of its rise in temperature. If a pointer is held in a position of equilibrium between turning moments produced by two wires pulling on opposite arms of a lever, the heating of one of these wires by an electric current will produce a change in the position of equilibrium. It is evident that change in the temperature of the room affects both wires alike and produces no change in the zero position. The deflection of a hot wire instrument is dependent on the square of the current (as the heating is proportional to the square of the current). For this reason the hot wire instrument deflects in the same direction for currents in either direction and for alternating currents as well. As the effective value of an alternating current is equal to the square root of the mean square, it is evident that a hot wire instrument calibrated by direct currents, will give proper readings for alternating currents also. Hot wire instruments are made use of as ammeters (low resistance) and voltmeters (high resistance). As a rule hot wire instruments are used for alternating currents. They are usually less accurate than electrodynamometers of the best types.

Wattmeters. We have seen that an electrodynamometer has a turning moment proportional to the square of the current passing through it. If the current passing through the fixed coil is different from that passing through the movable coil, the turning moment will be proportional to the product of these currents. If the power delivered to a line is to be measured, the average product of the volts and amperes gives the result in watts. The current delivered from the line to the load may be passed through one coil (usually of low resistance) whose terminals are *A* and *B*, Fig. 12, and the e. m. f. may be applied at the terminals of the other coil (usually of high resistance) whose terminals are *a* and *b*, and produce a second current proportional to this e. m. f. In order to avoid measuring the effect of the pressure current it is led backward through coil *F* shown in dotted line, thus subtracting its effect. The instrument may be calibrated to read watts. As a rule it is easier to make the second coil of moderate resistance and to insert a non-inductively wound high resistance coil *R* in series. If the wattmeter is to be calibrated by the use of current and e. m. f. in separate circuits, the terminals *i* and *b* are used. The resistance of *S* is equal to that of *F*. The currents in both coils will reverse if the e. m. f. is reversed, but the deflection will be unchanged. The average power of a varying current equals the average product of current and e. m. f.; consequently a wattmeter calibrated with direct currents gives correct results for alternating currents. If the current and e. m. f. are alternating, the mean product will in general be less than the product of the effective values of current and e. m. f. (as measured by A. C. voltmeters and ammeters); consequently when dealing with alternating current and e. m. f. the product must be multiplied by a factor, called the *power factor*, which is usually less than unity, if the correct value is to be computed from ammeter and voltmeter readings. As a rule the power factor is found by dividing the watts as measured by a wattmeter by the product of volts and amperes.

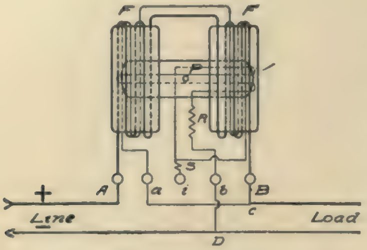


Fig. 12. Diagram of Wattmeter.

Recording Voltmeters and Ammeters. If any of the voltmeters or ammeters described above are arranged with a pen which traces a line on a disk or roll of paper drawn by clockwork past the pen, the instrument will record the variations of e. m. f. or current. There are several good types of recording voltmeters and ammeters on the market. A recording ammeter is shown in Fig. 13.

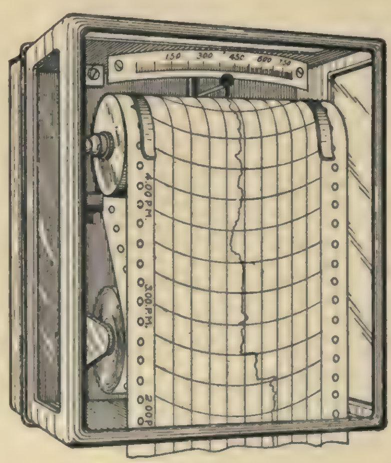


Fig. 13. Recording Ammeter.

Integrating Watt-Hour Meters. Integrating meters show the total consumption of the thing to be measured; for example, integrating gas meters show the consumption of gas in cubic feet. In the same way an integrating watt-hour meter (commonly, though inexactly, called an integrating wattmeter) shows the consumption of energy in watt-hours. Such an instrument is shown in Fig. 14. The instrument is essentially an electric motor geared to a train of wheels moving hands over dials. The speed of the motor is proportional to the power in watts, and the product of the average power and the time in hours (that is, watt-hours) is indicated by the change in the position of the hands on the dial since the last reading. To give correct readings the driving motor must be designed for the circuit on which it is used. The essential factors of the circuit are the e. m. f., maximum current, whether direct or alternating current is used, etc. In a three-wire system a single meter may be designed to measure the power of the two or three circuits involved.

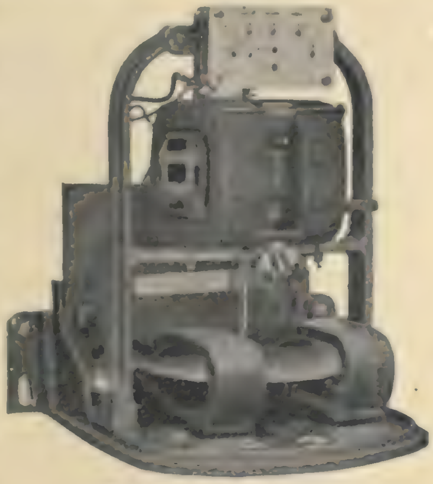


Fig. 14. Watt-Hour Meter.

Integrating Ampere-Hour Meters. An integrating ampere-hour meter (commonly called integrating ammeter) is similar to the watt-hour meter. It is used generally in connection with storage batteries to keep account of the charge and discharge. It is of little general use.

Rheostats and Resistance Coils. The word rheostat means an apparatus for stopping the current. In actual fact it does not wholly stop the current, but only reduces it to a desired extent. Every material interposes some resistance to the flow of an electric current. Substances interposing extremely high resistance are known as insulators, and those interposing relatively little resistance, as conductors. Metals, as a rule, are the best conductors. The metals most used commercially for electrical transmission are copper, aluminum, and iron (or steel). Alloys in general have much higher resistance than the metals of which they are composed. Carbon and solutions of various salts have much higher resistance than metals. Rheostats may be made of any of these materials, but those most generally used are steel wire or sheets, German silver wire or other alloys, carbon rods or plates, and solutions in tanks in which metal plates are immersed, the metal plates being connected to the terminals of the circuit. Such metal plates are known as electrodes. This last arrangement is usually called a *water rheostat*. Pure water has a very high resistance and is never used in water rheostats, but the resistance may be reduced as desired by dissolving salt in the water. The metal plates are usually arranged so that one electrode may be brought nearer the other when it is desired to increase the current. When the word rheostat is used, it is generally understood that the resistance is not exactly known. A rheostat is shown in Fig. 15.

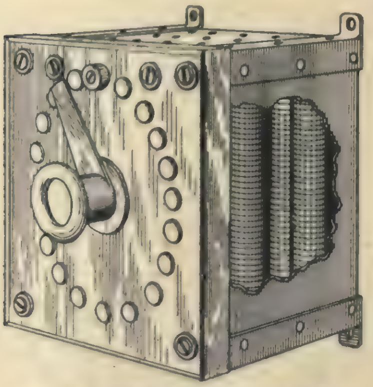
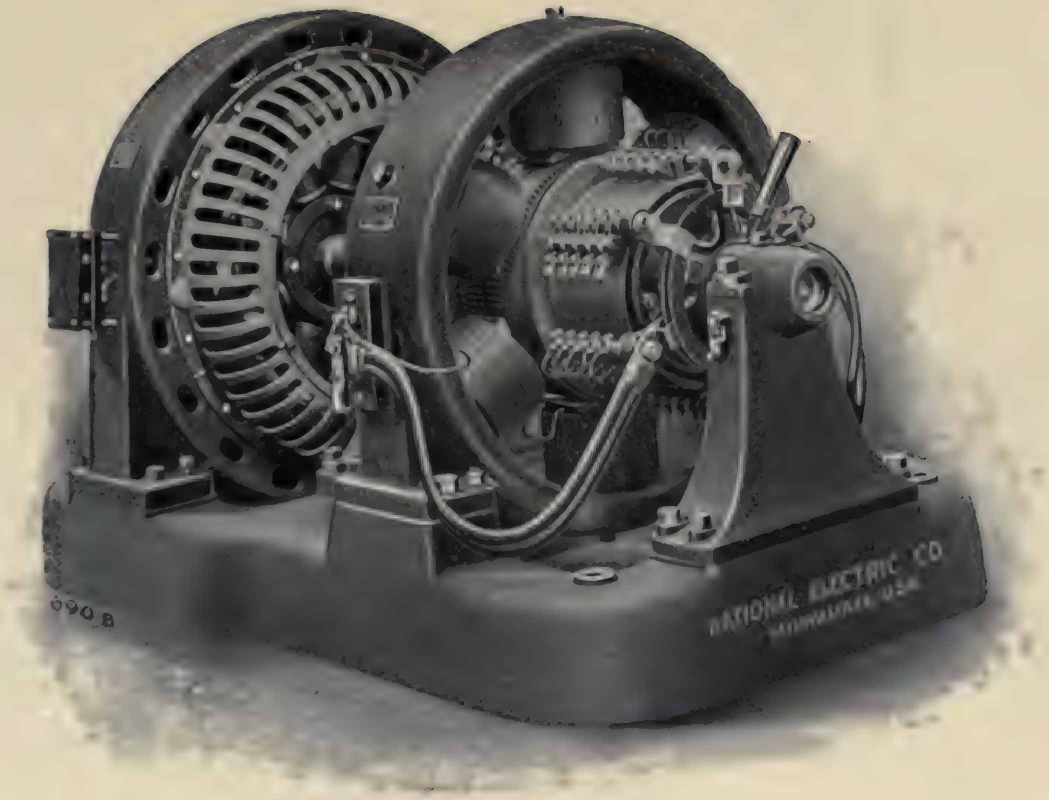


Fig. 15. Rheostat for Varying the Current in Any Circuit.

When it is desired that the resistance have a certain exact value, metals are the only practical materials to use. Coils of wire exactly adjusted are called *resistance coils*. They are adjusted to certain values in ohms. For very low resistances, *e. g.*, small fractions of an ohm, metal strips may be used. As most pure metals increase their resistance with increase of temperature by about 0.4% per degree centigrade, resistance coils are almost always made of certain alloys which change little in resistance with change in temperature. One alloy in particular, manganin, changes so little in resistance with change in temperature that it is usually chosen for standard *resistance* coils. Figs. 16 and 17 show standard resistances in the form of a coil and a strip. As mentioned above alloys have relatively high resistance and for this reason also the alloy manganin is preferable to any pure metal for resistances.

Lamp Rheostats. A very convenient form of carbon rheostat is a bank of incandescent lamps. The usual 16 c. p. lamp for a 110-volt circuit has a resistance when hot of about 220 ohms. Its resistance when cold is about twice as much. Carbon and solutions, unlike metals, are better conductors when hot than cold. It is evident that incandescent lamps, because of their change in resistance from cold to hot, are not suitable for standard resistances. If two lamps



"NATIONAL" MOTOR-EXCITER SET.

60 K.W. 900 R.P.M.

are arranged in series, *i. e.*, if the current is made to pass through one after the other, the resistance of the combination is twice that of a single lamp. On the other hand if the lamps are connected in parallel, *i. e.*, if the current divides between them, the resistance of the combination is only half of that of a single lamp. This result is evident as the same e. m. f. produces twice as much current in two lamps as in a single one. In the same way ten lamps in parallel have a combined resistance only one-tenth as much as a single lamp.

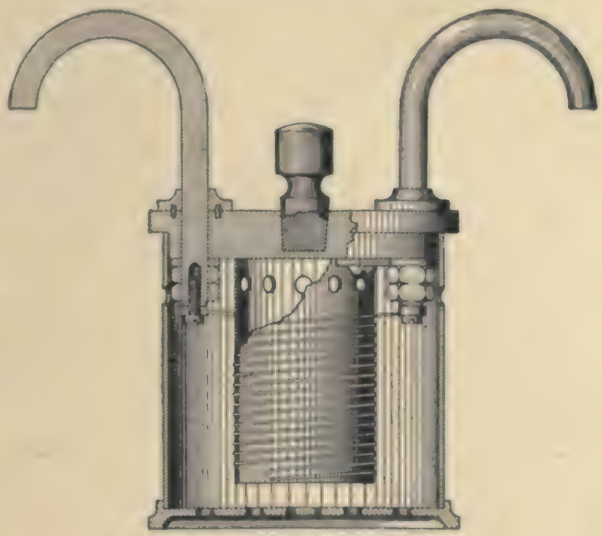


Fig. 16. A Standard Resistance Coil.

Multiplying Power of Shunts. The word shunt is the British name for a side track (or as we would call it, switch) on a railway. Any electrical side path is called a shunt. If the current has two or more paths in parallel offered to it, the current divides in inverse proportion to the resistance or, as more simply expressed, in direct proportion to the conductivity of the various paths. Thus if a galvanometer has a shunt across its terminals whose resistance is one-ninth of that of the galvanometer, nine times as much current will go through the shunt as through the galvanometer and consequently only one-tenth of the current will go through the latter. The total current is then ten times the current through the galvanometer and we

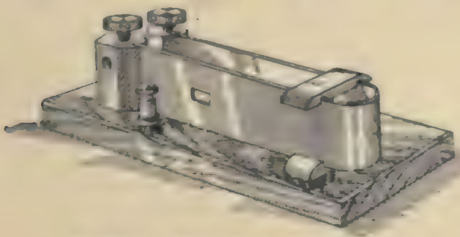


Fig. 17. A Standard Resistance Strip.

say that the multiplying power of the shunt is ten. If the galvanometer has a shunt of one ninety-ninth of the former's resistance, one one-hundredth of the current will pass through the galvanometer and the multiplying power of the shunt will be one hundred. In general, if the resistance of the shunt is $\frac{1}{m-1}$ of that of the galvanometer, the multiplying power of the shunt will be m. The evident effect of the shunt is to reduce the resistance of the galvanometer circuit to $\frac{1}{m}$ of its former value, *i. e.*, to $\frac{1}{m}$ of the resistance of the galvanometer itself; the resulting fall of potential over the galvanometer and shunt is, therefore, only $\frac{1}{m}$ as much as if the shunt were not there. Galvanometers are provided by their makers, if desired, with shunts having a multiplying power of 10, 100, and 1,000, marked to go with the particular galvanometer. It is evident that the usual shunt cannot be used with other galvanometers without recalculation of its multiplying power, which under such circumstances would probably be some inconvenient number.

Professor Ayrton has devised a form of shunt box with extra resistance which is automatically connected in series in proper amount to keep the total resistance constant but allowing only $\frac{1}{10}$, $\frac{1}{100}$, or $\frac{1}{1000}$ of the current to pass through the galvanometer.

OHM'S LAW

In 1827, Dr. G. S. Ohm of Berlin published a treatise, now famous, entitled *The Galvanic Circuit Investigated Mathematically*, in which he announced the fundamental law of electric circuits now known as Ohm's law. This is usually stated in the algebraic formula:

$$I = \frac{E}{R}$$

In words, the current (in amperes) equals the e. m. f. (in volts) divided by the resistance (in ohms). It is truly a surprising fact that the resistance of an electric circuit is a constant not dependent on the current passing. Many experimenters have tried in vain to find any inaccuracy in Ohm's law. If any two of the three quantities involved are known, the third may be found by solving the equation. Thus,

$$I = \frac{E}{R},\ R = \frac{E}{I},\ \text{and}\ E = I\,R$$

As will be seen later, one of the most convenient methods of measuring low resistances, as of a dynamo armature, is a simple application of Ohm's law.

MEASUREMENT OF RESISTANCE

Resistance Boxes. Measurement of resistance is made by comparison with certain standards of known resistance, the different methods of measurement varying to a great degree. The standard resistance coils are made of such alloys as manganin—an alloy of manganese copper and nickel—which has a high specific resistance and changes its resistance with rise in temperature to a much less extent than other metals. It is of course desirable that this change should be as small as possible. The size and length of the coils are such that they have resistances of a definite number of ohms at a certain temperature. The coils are insulated with silk or paraffined cotton and are very carefully wound. Each wire is doubled on itself before being coiled up, and then wound as shown at *A* and *B* in Fig. 18; or, as is sometimes preferred, the wire may be wound single in layers, the direction of winding being reversed for alternate layers. Inductance and capacity effects are by these means reduced to a minimum. The ends of the coils are soldered to brass pieces as *C*, *D*, *E*. Removable conical plugs *F* and *G* of brass are made to fit accurately between the brass pieces. When these are inserted as shown, the coils will be short circuited and a current will pass directly through *C*, *F*, *D*, *G*, and *E* without going through the coils. If *F* is withdrawn the coil *A* will then be inserted in the circuit; if *G* is also withdrawn then coils *A* and *B* will both be inserted, as the current cannot pass from *C* to *E* without going through the coils.

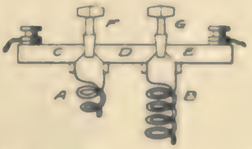


Fig. 18. Resistance Box Coils Showing Non inductive Winding.

Resistance boxes are constructed consisting of a large number of resistance coils, and of such resistances that by withdrawing plugs varying resistances may be built up. A common form of resistance box has coils of the following ohms resistance: 1, 2, 2, 5, 10, 20, 20, 50, 100, 200, 200, 500, 1,000, 2,000. A resistance of 497 ohms could be made up by withdrawing plugs corresponding to the coils 200 + 200 + 50 + 20 + 20 + 5 + 2 = 497, or 768 by coils 500 + 200 + 50 + 10 + 5 + 2 + 1 = 768.

Resistance by Substitution. By Ohm's law the greater the resistance inserted in a circuit the less becomes the current, provided the e. m. f. remains constant. This gives us a simple although not very accurate method of measuring electrical resistance. If a battery of constant e. m. f., the unknown resistance, and a simple galvanometer are connected in series, the strength of the current passing will be indicated by the latter. Suppose the unknown resistance to be replaced by known resistances, enough resistance coils being inserted so that the deflection of the galvanometer needle is the same as when the unknown resistance was in circuit. The current will then be the same, and as the e. m. f. remains unchanged, the resistances must be equal in each case. The sum of the known resistance coils inserted will then be equal to the unknown resistance.

The advantages of this method are that it is rapid, and that only crude apparatus is required, as the galvanometer and resistance box can be very simple in form. The resistance of the battery and galvanometer should be but a few ohms, otherwise small resistances cannot be measured closely. Only small currents should be used so that the error from heating may be negligible.

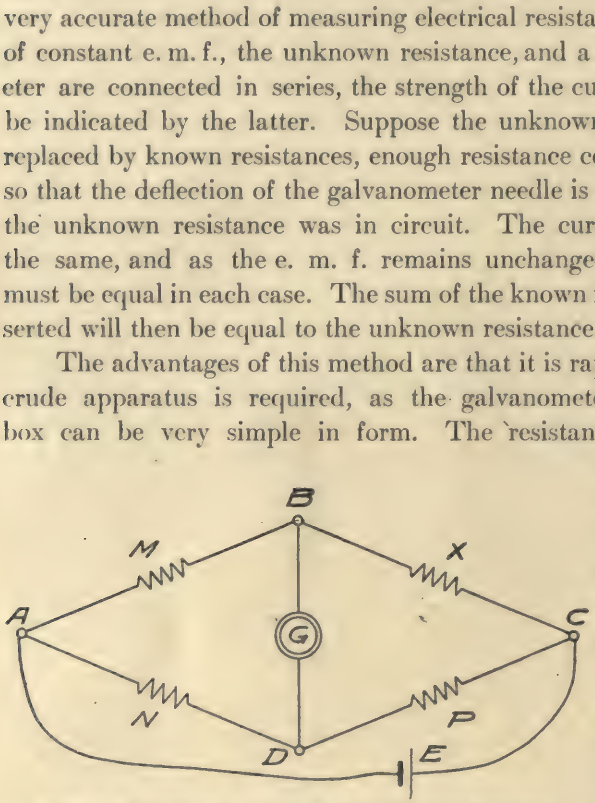


Fig. 19. Theoretical Diagram of a Wheatstone's Bridge.

Wheatstone's Bridge. All ordinary measurements of resistance are usually made by use of a Wheatstone's bridge.

The principles of this instrument will be understood from Fig. 19. There are four arms to the bridge with the resistances M, N, X, and P. From the points of junction A and C, wires connect with a battery E. A galvanometer G is connected between the junction points B and D. The current from the battery divides at A and passes through the resistances M and X, and N and P, uniting again at C. The fall of potential between A and C must of course be the same in amount through the resistances M and X as through N and P. If no current passes through the galvanometer then the points B and D will be at the same potential, and there will be the same fall of potential in the resistances M and N, and in the resistances X and P. Under these circumstances the ratio of the resistances of M to N will be the same as X to P, or

$$\frac{M}{N}=\frac{X}{P}$$

If M, N, and P are known resistances, the resistance of X is readily found by the formula,

$$X=\frac{M}{N}\times P$$

The method of using the bridge will be better understood from Fig. 20. The bridge arm M has coils of 1, 10, 100 ohms resistance, and arm N, coils 10, 100, 1,000. The series of coils P for obtaining a balance usually has resistances of 1, 2, 2, 5, 10, 20, 20, 50, 100, 200, 200, 500, 1,000, 2,000 ohms, but coils up to 100 only are shown. There is a key K in the galvanometer circuit and a key H in the battery circuit. The battery key H should always be closed *before* the galvanometer key K, and should be kept closed until after K is opened. This not only insures steadiness in all currents when the galvanometer circuit is closed, but also protects the galvanometer from self-induction currents which would occur if the battery circuit were closed after that of the galvanometer. A double successive contact key, Fig. 21, may with advantage be substituted for the two single keys, thus insuring that the battery and galvanometer branches will be closed and opened in the proper se-

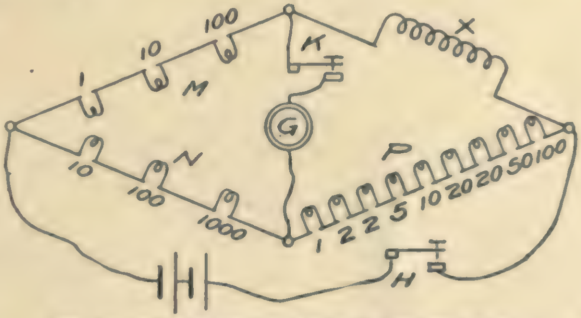


Fig. 20. Diagram Showing Method of Making Bridge Measurements.

quence. A reflecting galvanometer is used for accurate measurement

In making a measurement of an unknown resistance it is first necessary to gain a knowledge of its approximate resistance. For this purpose the 100-ohm plug is withdrawn from both arms *M* and *N*, the unknown resistance being connected at *X*. The ratios of *M* to *N* will then be unity, and hence for a balance the number of ohms required in the resistance coils *P* will be the same as the resistance *X*. The 1,000-ohm plug in *P* should first be drawn and the keys depressed in their proper order for an instant only. The galvanometer needle or mirror, as seen by the light reflected on the scale, is deflected—say to the right, and the resistance is probably too large. The plug is replaced and the 1-ohm coil withdrawn. On depressing the keys suppose the spot of light is deflected to the left. Then the 1 ohm is too small and the 1,000 ohms too large; also in this case deflections to the right mean that the resistance inserted is too large, and to the left, that the resistance inserted is too small. The 1-ohm plug is now replaced, and 500, 200, etc., are successively tried until it is found that 12 ohms is too large and 11 ohms too small, that is, the unknown resistance is between 11 and 12 ohms.

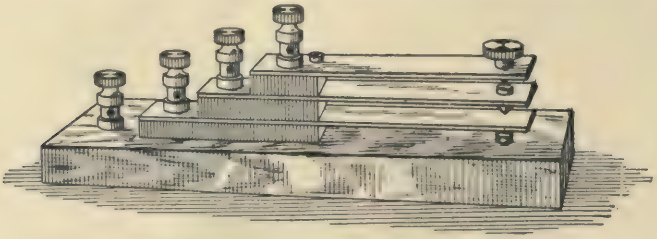


Fig. 24. 4-Point Contact Key.

Suppose that it is desired to find the correct value of the unknown resistance to the second place of decimals. The ratio of the arms *M* to *N* must then be changed so that the resistance coils *P* will have a value of between 1,100 and 1,200 ohms when a balance is obtained. The ratio of *X* to *P* will then be 11 to 1,100 approximately, or about 1 to 100. To obtain a balance the ratio of the arms *M* to *N* must also be 1 to 100. Hence the 100-ohm plugs first withdrawn are replaced and the 10-ohm plug withdrawn from *M* and the 1,000-ohm plug from *N* giving the required ratio. The same ratio could be obtained by withdrawing the 1-ohm plug in *M* and the 100-ohm plug in *N*.

The bridge is now arranged for the final measurement. As the resistance in *P* will now be over 1,100 ohms, the 1,000- and 100-ohm plugs are first removed. Suppose the 50-ohm plug to be also removed, and a deflection to the right shows that this is too great. The plug is replaced and 20 withdrawn, which proves to be too small. The next twenty plug is also withdrawn and a deflection to the left shows the resistance to be still too small. The 5-, 2-, and 2-ohm plugs are successively withdrawn, the last two ohms proving to be too great. This is replaced and the 1-ohm plug withdrawn, and suppose no deflection is then obtained. The total number of ohms in *P* is now $1,000 + 100 + 20 + 20 + 5 + 2 + 1 = 1,148$. The value of *X* is therefore $\frac{1}{100} \times 1,148 = 11.48$ ohms.

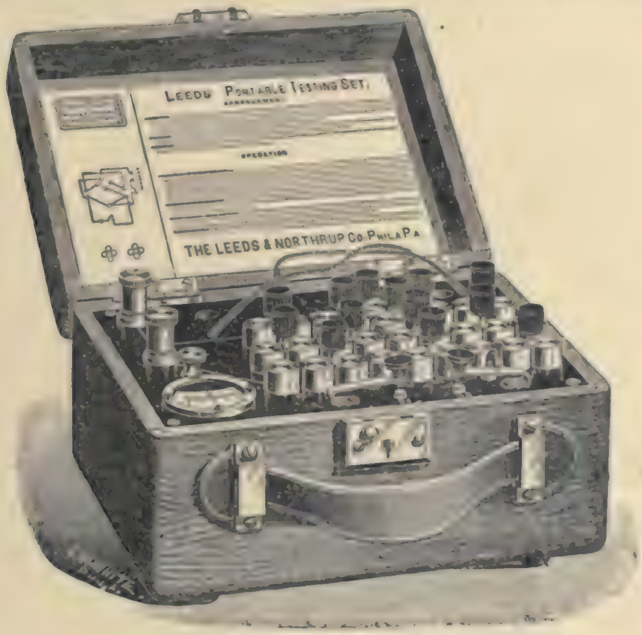


Fig. 22. Portable Testing Set.

The above example illustrates the general method of using the bridge. Usually the resistance to be measured is known approximately and the required ratio between *M* and *N* can be determined without making a preliminary measurement. The possible changes in the ratio between *M* and *N* gives the bridge a great range of measurement. When *M* is 1 and *N* is 1,000 ohms, measurements of resistance as small as .001 ohm may be made. Bridges are usually arranged with a reversing key so that M and N may be interchanged, hence M could be 1,000 and N 1, and measurements of resistance as high as 4,110,000 ohms could be made with the bridge we have considered.

Portable Testing Set. There are many different varieties of bridges and their form always differs from that of the diagrams in Figs. 19 and 21. A portable testing set including Wheatstone's bridge, galvanometer, battery, and keys, is illustrated in Fig. 22. The rheostat of the bridge is made up of coils, 16 in number, of denominations 1, 2, 3, 4, 10, 20, 30, 40, 100, 200, 300, 400, 1,000, 2,000, 3,000, 4,000 ohms—11,110 ohms in all. Bridge coils are 1, 10, and 100 on one side and 10, 100, and 1,000 on the other. A reversing key admits of any ratio being obtained in either direction so that the range of the set is from .001 to 11,110,000 ohms. It is, however, impossible to construct a portable galvanometer of sufficient sensitiveness for these measurements, and the actual limits are from .001 ohm to 300,000 or 400,000 ohms.

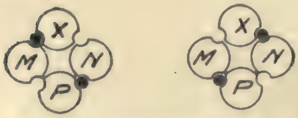


Fig. 23. Reversing Keys.

The reversing key, shown in Fig. 23, consists of the blocks M, N, P, and X and two plugs which must both lie on one diagonal or the other. The blocks are connected with the resistances indicated by their letters. In the left-hand figure M is connected with X and N with P, and the bridge arms have the relation

$$\frac{M}{N} = \frac{X}{P}, \text{ or } X = \frac{M}{N} \times P$$

In the right-hand figure M is connected with P and N with X, the bridge arms then having the relation

$$\frac{M}{N} = \frac{P}{X}, \text{ or } X = \frac{N}{M} \times P$$

The advantages of having a reversing key in the bridge arms are: the increase in range obtained, six coils being made to do the work of eight, and also that any error in the initial adjustment of the bridge arms can be detected by having the two arms equal, balancing and reversing. Unless the resistance of the coils inserted in M and N are exactly equal, the system will be unbalanced after reversing.

The galvanometer, the needle and scale of which are shown at the left in Fig. 22, is of the D'Arsonval type, and the coil is mounted in jewels. As this galvanometer is not affected by external magnetic fields or electric currents, it is suitable for dynamo or shop testing. The key for the galvanometer circuit is shown in front at the right.

The battery is made up of chloride of silver cells mounted in the bottom of the box. The cells will last a number of months even with daily use. Flexible connecting cords, running from the cells, have their terminal sockets combined with small binding posts so that connection may be made to an extra battery or other source of e. m. f. if desired. The left-hand key controls the battery circuit.

A plan of the connections of this testing set is shown in Fig. 24. The two lower rows of coils (marked 1 to 4,000) are connected beneath the top at the right by a heavy copper rod and constitute the rheostat arm, or what corresponds to *P* in the formula. By withdrawing the proper plugs in these rows any number of ohms from 1 to 11,110 may be obtained. The upper row of coils consists of the two bridge arms, *M* at the left and *N* at the right, with the reversing key between them. The two extremes of the upper row are joined by a heavy copper connection and correspond to the point *A* in Fig. 19. The upper block *X* of the reversing key is connected with the binding post *B*, the block *P* is joined to the left of the middle row of coils while the other end of the rheostat combination is connected with the binding post *C*. The resistance to be measured *X* is connected between the terminals *B* and *C*.

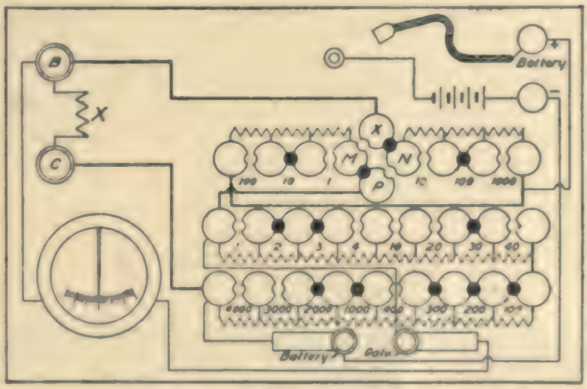


Fig. 24. Diagram of a Testing Set.

Example. Suppose a balance is obtained with an unknown resistance connected between *B* and *C*, when the plugs are withdrawn as shown in Fig. 24. What is the value of the unknown resistance?

Solution. The reversing key is arranged so that M is connected with P and N with X, hence

$$\frac{M}{N} = \frac{P}{X}, \text{ or } X = \frac{N}{M} \times P$$

In the figure $N = 100$, $M = 10$, and $P = 2{,}000 + 1{,}000 + 300 + 200 + 100 + 30 + 3 + 2 = 3{,}635$. Therefore

$$X = \frac{100}{10} \times 3{,}635 = 36{,}350 \text{ ohms}$$

Ans. 36,350 ohms.

Use and Care of Bridge. Before beginning a measurement it is essential that each plug be examined to see that it is firmly twisted into place, also in replacing a plug the same care should be used. A slight looseness will considerably increase the contact resistance and so introduce errors in the result. Moderate force only is needed in placing plugs. A strong person may damage the apparatus. For the same reason the plug tapers should be kept clean and the top of the bridge should be free from dust and moisture. Special care should be taken with the surfaces between adjacent blocks. The plugs should be handled only by their vulcanite tops, and care should be taken not to touch the blocks.

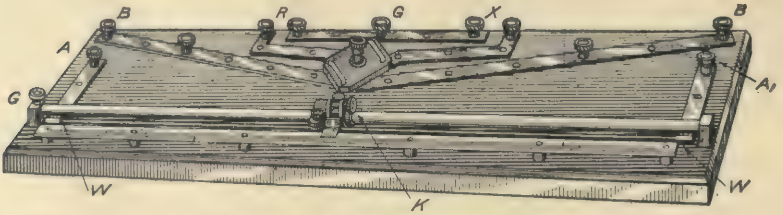


Fig. 25. Slide Wire Wheatstone's Bridge.

The plug tapers may be cleaned with a cloth moistened with alcohol and then rubbed with powdered chalk or whiting. The powder should be entirely removed with a clean cloth before the plugs are replaced. Sand paper or emery cloth should never be used to clean the plugs or bridge blocks. If there are no idle sockets for the reception of the plugs when they are withdrawn, they should be stood on end or placed on a clean surface.

Slide Wire Bridge. The simplest form of Wheatstone's bridge is the slide wire bridge. Fig. 25 illustrates the apparatus. The foundation of the bridge is a board well braced to avoid warping, which, after being well dried, is saturated with hot paraffin to make it a good insulator. The bridge wire is usually one meter long and stretched between substantial anchorages at the ends. Heavy straps of copper or brass serve as connections of negligible resistance to the other parts of the bridge. The known resistance is inserted at R and the unknown at X. Openings at A and A' are closed by heavy metal straps for the usual method of use, or in more complete methods by resistances which are, in effect, extensions of the bridge wire. The battery and its key are connected between B and B, and the galvanometer between G and G. The heavy rod back of and above the bridge wire is a support for the galvanometer key K and the index which is adjacent to the meter scale shown. The key and the index may be moved along the rod to find the balancing point. A commutator shown at the center of the apparatus serves to exchange the relative position of X and R in the arrangement. The commutator makes connection in four mercury cups. If the portion of the bridge wire to the left of the galvanometer key is a cm. long, the rest of the wire is 100-a long. If the commutator is arranged so that R is connected to the left end and X to the right end of the wire, when a balance is reached we have

$$\frac{R}{X} = \frac{a}{100 - a}, \text{ or } X = R\,\frac{100 - a}{a}$$

If the commutator is reversed and the new reading is a' we get

$$X = R\,\frac{a'}{100 - a'}$$

If the balancing point is near the end of the wire, it is evident that any small error in the reading and the assumption that the connections are of negligible resistance, will result in greater error in the final formula. For this reason it is well to treat the first balance as only approximate and after calculating X to take as known resistance a new value of R as nearly as possible equal to X. In this way the balancing point will be brought near the center of the wire.

For very exact comparison of two nearly equal resistances, we insert auxiliary resistances at A and A'. These are in effect extensions of the bridge wire. Call these resistances equal to A and A' cm. of the wire. When a balance is obtained at the points a and a' for the two positions of the commutator, we have

$$X = R\frac{A' + 100 - a}{A + a} \text{ and } X = R\frac{A + a'}{A' + 100 - a'}$$

While it is still of advantage under these conditions to have a and a' somewhere near 50 cm. it is no longer necessary, for with the bridge wire extended by A and A' any point of the actual bridge wire is now near the center.

If R is materially larger or smaller than X, the balancing point may be beyond the end of the actual wire, *i. e.*, in one of the extensions, and no balance can be obtained. It is necessary then to adjust R until a balancing point is found on the wire. We may then proceed with the experiment.

A variation of this method, known as the *Carey-Foster method*, is used for the comparison of two standard resistances to discover small differences in adjustment.

Example. If with the openings A and A' closed with straps of negligible resistance and a resistance of 150 ohms for R, the mean balance point comes so that a = 68.4 cm. and b = 31.6 cm., what is the value of X? Ans. 69.3 ohms.

Example. If A and A' are equivalent to 500 cm. each, and R = 150 ohms, and the mean balance point makes a = 68.4 cm., and b = 31.6 cm., what is the value of X? Ans. 140.29 ohms.

Low Resistance Measurement. The bridge methods described above are not suitable to use in the measurement of small resistances, for the *lead* wires (*leading in* wires) used in connecting the unknown resistance to the *bridge* may have more resistance than the unknown. The *ammeter-voltmeter method* is that most generally used. The apparatus is connected as shown in Fig. 26. The current from the battery is led through the ammeter to the unknown low resistance R. An adjustable resistance r of a rheostat may be introduced into the circuit to control the current. The actual resistance r need not be known. The fall of potential V through R is measured by the voltmeter, and the current I by the ammeter. Ohm's law then gives

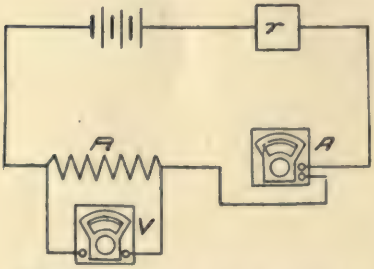


Fig. 26. Ammeter-Voltmeter Method of Low Resistance Measurement.

$$R = \frac{E}{I}$$

Ammeter-Voltmeter Method. It is evident that although the voltmeter is of very high resistance, a small current included in that measured by the ammeter passes through the voltmeter. In strictness this current, equal to $\frac{V}{\text{resistance of the voltmeter}}$, should be subtracted from the ammeter reading to get the value of I to be used in the formula. This correction is easily made, as all makers of voltmeters give the value of the resistance, usually marked on the voltmeter case; but the error resulting from neglecting the correction is generally immaterial. Instruments of suitable range should be used.

Example. The reading of the ammeter is 50 amperes, that of the voltmeter 1.5 volts; what is R? Ans. 0.03 ohm.

In the particular case chosen the ammeter had a range 0 to 75 amperes, and the voltmeter 0 to 3 volts. The resistance of the voltmeter was 300 ohms. The current through the voltmeter was $1.5 \div 300 = 0.005$ amperes. It is evident that the correction is far smaller than the probable error of reading the ammeter, and any attempt at correction would be absurd.

This method may also be used to measure the resistance of a burning incandescent lamp. In such a case the bridge method is useless as the resistance of a cold lamp is probably double its resistance when hot.

Example. The voltmeter, 0 to 150 volts range and resistance 15,000 ohms, reads 110 volts; the ammeter, 0 to 1 amperes range, reads 0.5 ampere. What is the resistance R? Ans. 220 ohms.

High Resistance Measurement. *Direct Deflection Method.* An excellent method of measuring resistances of one megohm (one million ohms) or more, is the direct deflection method. The main instruments needed are a sensitive galvanometer, usually of high resistance and fitted with appropriate shunts; some standard resistances of 100,000 ohms (0.1 megohm) or more; and a battery of relatively low resistance and constant e. m. f. (a storage battery of many cells, if available). The resistance of the galvanometer both alone and combined with its shunts must be known. That of the battery and the connections is usually neglected. The connections are shown in

Fig. 27. The known resistance R is first connected in series with the galvanometer G and the testing battery B, through a key K. Care should be taken that the insulation of the apparatus be very high. The shunt S is adjusted to give a suitable deflection of the galvanometer and from this deflection what is known as the *constant* is calculated. The value of this constant is the resistance that must be inserted in the circuit to reduce the deflection to one scale division. The value of the constant is therefore equal to the product of the total resistance, assumed to be $R + \frac{G}{m}$, the scale deflection d, and the multiplying power of the shunt m. We thus get

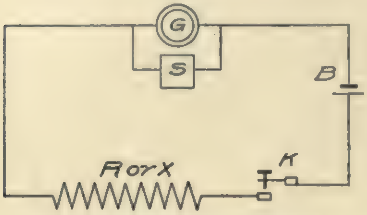


Fig. 27. Direct-Deflection Method of High Resistance Measurement.

$$\text{Constant} = (R + \frac{G}{m})\, d\, m$$

As an illustration, suppose $R = 0.1$ megohm, $G = 20{,}000$ ohms $= 0.02$ megohm, $m = 1{,}000$, and $d = 200$ divisions; then

$$\text{Constant} = (0.1 + 0.00002) \times 200 \times 1{,}000$$
$$= 20{,}004 \text{ megohms}$$

This means that if the galvanometer were unshunted and the total resistance in the circuit were 20,004 megohms, a deflection of one division would result.

After the constant has been determined the known resistance R is replaced by the unknown resistance X. The galvanometer shunt is readjusted if necessary and the deflection obtained is again noted. The value of the total resistance is then found by dividing the value of the constant by the product of the deflection d_1 and the multiplying power m_1 of the shunt used. To continue our illustration suppose $d_1 = 50$ divisions, and $m_1 = 10$. The deflection, if the full current went through the galvanometer, would be $50 \times 10 = 500$ divisions. A deflection of one division is produced with a resistance of 20,004 megohms; hence a deflection of 500 divisions must correspond to $\frac{1}{500}$ of this, or 40.008 megohms. Subtracting the resistance of the shunted galvanometer $20{,}000 \div 10 = 2{,}000$ ohms, or 0.002 megohm, leaves the unknown resistance 40.006 megohms. The algebraic equation expressing this is

$$X = \frac{\left(R + \frac{G}{m}\right) d\, m}{d_1\, m_1} - \frac{G}{m_1} = 40.006 \text{ megohms}$$

Neglecting the resistance of the galvanometer in both cases, a simpler formula would give

$$X = \frac{R\, d\, m}{d_1\, m_1} = 40 \text{ megohms}$$

It may be noted that the difference between these results is an amount corresponding to a difference in deflection of 0.0075 of a single scale division, which is far smaller than the probable error which any observer would make. It is then clearly permissible to use the simpler formula,

$$X = \frac{R\, d\, m}{d_1\, m_1}$$

Example. In a high resistance measurement by the above method the known resistance was .2 megohms, and gave a deflection of 237 divisions, the multiplying power of the shunt being 100. With the unknown resistance inserted, the deflection was 178 divisions with the full current passing through the galvanometer. What was the value of this resistance? Ans. 26.6 megohms.

Voltmeter Method. Another method of measuring high resistance is that in which a sensitive high resistance voltmeter such as the Weston is used. This method, however, is not as accurate as the preceding and is not adapted to measurements of resistance greater than a few megohms. The voltmeter is connected in series with the unknown resistance and a source of constant e. m. f., as shown in Fig. 28. With such an arrangement the resistance X will be to the resistance of the voltmeter R, as the volts drop in X is to that in the voltmeter. The drop v in the voltmeter is given by its reading, and if the applied electromotive force V is known, the drop in X will be $V - v$. We therefore have the proportion,

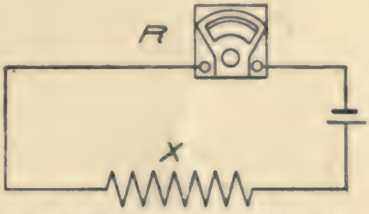


Fig. 28. Voltmeter Method of High Resistance Measurement.

$$X : R :: V - v : v, \text{ and}$$

$$X = \frac{V - v}{v} \times R$$

The voltage V, which should be at least 100, may be first determined by measurement with the voltmeter.

Example. A voltmeter having a resistance of 15,000 ohms, was connected in series with an unknown resistance. The e. m. f. applied to the circuit was 110 volts and the voltmeter indicated 6 volts. What was the value of the unknown resistance?

Solution. Applying the preceding formula

$$V = 110,\ v = 6, \text{ and } R = 15{,}000,$$

therefore

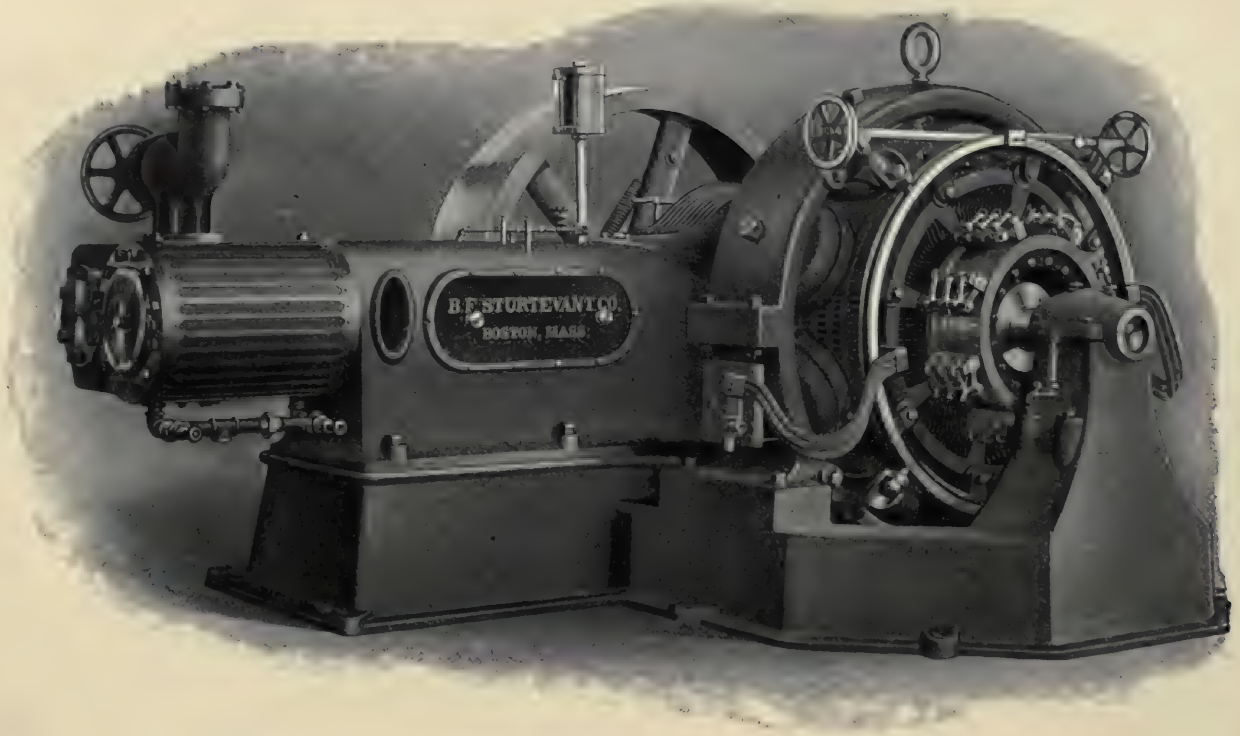
$$X = \frac{110-6}{6} \times 15{,}000 = 260{,}000 \text{ ohms, or } .26 \text{ megohms}$$

Ans. .26 megohms.

Insulation Resistance. The measurement of insulation resistance is performed by either of the two preceding methods of measuring high resistance. The voltmeter method is the simpler, but since it cannot be used to measure resistances greater than a few megohms, the direct deflection method proves to be the more valuable. The insulation of low potential circuits, however, need not exceed five megohms, and in testing such circuits the voltmeter method may be used. If little or no deflection is obtained it is then evident that the insulation is at least several megohms, which is all that is desired. As the insulation of high potential circuits must be greater than five or ten megohms, the direct deflection method should then be used.

The *connections* in testing the insulation of a circuit by these two methods are similar to those shown in Figs. 27 and 28, the resistance X being replaced by the insulation of the circuit. This is accomplished by connecting one wire to the line and the other to the ground such as, to a gas or water pipe. The insulation of the line from the earth is then included in the testing circuit; the current passing from the battery, or other source, through the voltmeter or galvanometer to the line, from the line through the insulation to the ground, and then to the battery.

The insulation of a dynamo, that is, the resistance between its conductors and its frame, is tested in a similar manner. This resistance should be at least one megohm for a 110-volt machine, but two megohms is to be preferred and is customary. This insulation is measured by connecting one wire to the frame and the other to the binding post, brushes, or commutator. The insulation is then included in the circuit. Insulation resistance decreases with increase of



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temperature so that this test of a machine should be made after a full load run of several hours.

The e. m. f. used should be constant and of one to two hundred volts value. Secondary batteries are the best for this purpose but silver chloride testing cells are much used. The resistance of dielectrics increases by continued action of the current and this property is known as *electrification*. For this reason the deflection should not be read until after a certain period of electrification—usually one minute. This action is quicker in some materials than in others, and is also greater at low than at high temperatures.

Insulation Resistance of Cables. In the preceding cases of insulation resistance only a part of the insulation is under electric strain. In the case of submarine cables and lead covered cables used on land, the whole of the insulation is subjected to the electric strain. To test the resistance of a waterproof insulation, the insulated wire or cable may be immersed in a tank of water. Care should be taken to leave enough of the cable out of the water so that surface leakage near the ends may not interfere with the test. For short lengths of cable the resistance of the wire inside the insulating material may be ignored. The resistance between the wire and a metal plate immersed in the tank is practically the resistance of the insulation. Fig. 27 shows the arrangement of the apparatus. As a cable takes a certain charge as a condenser when subjected to an e. m. f., it is necessary to protect the galvanometer, by a short-circuiting switch between the galvanometer terminals, during the rush of current on first closing the circuit. The switch box *S*, Fig. 27, has such a short-circuiting switch. This is important as otherwise the galvanometer may be injured. If the insulation resistance is not too high the direct deflection method above described may be used. If the insulation is excellent the deflection produced by the leakage should be very small and some other method must be used.

Charge and Recharge Method. An excellent method in such cases is the charge and recharge method. In this method, Fig. 27, the cable is first charged for several minutes, care being taken to short-circuit the galvanometer. The circuit is then opened for, say, one minute and the circuit closed again, the short-circuiting switch of the galvanometer meanwhile having been opened. While the circuit was open, a certain part of the charge leaked out and this is now replaced by an equal added charge. The galvanometer makes a sudden throw due to this added charge and after many oscillations comes to rest. If the relation between the added charge and the galvanometer throw is known, the quantity added may be computed, and the leakage current is equal to the added charge (equal to that lost) divided by the time in seconds for which the circuit was open. If the steady leakage produces a measurable deflection, account should be taken of this in estimating that part of the sudden throw produced on closing the circuit again. This correction we here suppose to be negligible. To find the relation between charge and throw, a condenser of known capacity (farads) is charged by a known e. m. f. and then discharged through the galvanometer. The charge equals the product of capacity and e. m. f. used. The charge divided by the throw produced, gives the constant of the instrument as a ballistic galvanometer. As condensers are rated in microfarads (millionths of farads) care must be taken to use the value in farads if the value in ohms insulation resistance is required. If the value in microfarads is used, the final result will come out in megohms. If an e. m. f. E_1 volts and capacity C microfarads produces a ballistic throw d_1, and if an e. m. f. of E_2 volts produces a throw of d_2 on closing the circuit through the insulation under test after the circuit has been open for t seconds, ignoring the resistance of other parts of the circuit, the insulation resistance is

$$X = \frac{E_2 \times d_1 \times t}{E_1 \times d_2 \times C} \text{ megohms}$$

Example. If E_1 is 1.44 volts, C is 0.5 microfarad, d_1 is 28.8 cm., E_2 is 100 volts, d_2 is 20 cm., and t_1 is 60 seconds, what is X?

Ans. 12,000 megohms.

As a rule the insulation resistance per mile is required. The longer the cable the more surface is exposed to leakage; consequently it is evident that the insulation resistance per mile is found by multiplying the resistance of the sample by its length in fractions of a mile. That is, a mile of cable would have, say, one-quarter as much insulation resistance as a quarter of a mile of cable.

In the case of lead covered cables, no tank is required, as connection may be made with the lead covering instead of the immersed metal plate before mentioned.

Resistance of Lines. Telegraph, telephone, and power transmission lines may be measured in place to best advantage if one or more additional lines are available between the terminals. If only one wire is available both ends may be connected to ground and the resistance, which involves that of the connections to ground and that of the earth return, may be measured by one of the methods described above. Such a method though unsatisfactory may be the best available. The resistance of the earth return is generally low, but there is always much uncertainty as to the resistance to earth at the ends. Earth currents of electricity, due to many causes, may much complicate the problem. When a second line of resistance X_2 is available, that and the unknown resistance X_1 may be connected together at the distant end and the combined resistance R, which equals $X_1 + X_2$, measured. Next, the distant junction may be grounded and the two wires connected as the proportional arms of a Wheatstone's bridge, as illustrated in Fig. 29. The resistances in the other proportional arms are R_1 and R_2. One terminal of the battery is grounded. When a balance is obtained the proportion of the whole resistance R in X is

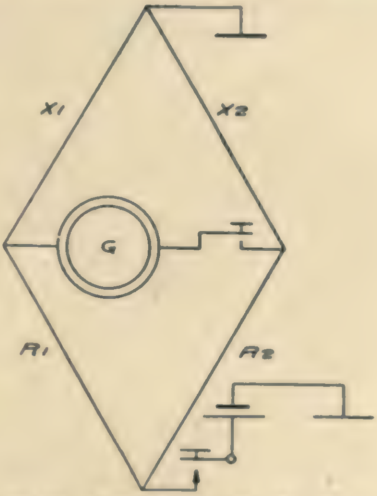

Fig. 29. Bridge Diagram for Line Resistance Measurement.

$$X_1 = R \frac{R_1}{R_1 + R_2}$$

In a similar way, $X_2 = R \frac{R_2}{R_1 + R_2}$

It is well to connect the battery in that branch of the bridge which includes the earth return as there may be a difference of potential due to earth currents, which does not disturb the *bridge* as it simply adds to or subtracts from the battery e. m. f. If a third line is available it may be used in the battery branch in place of the earth return. It will be noted that the resistance to earth at both ends is not in any of the four proportional arms and consequently does not affect the result.

Example. The two wires looped together have a resistance of 248 ohms. When a balance is obtained with them as arms of the bridge, $R_1 = 1{,}000$ ohms and $R_2 = 1{,}127$ ohms, the proportion being $R_1 : R_2 : : X_1 : X_2$. What are X_1 and X_2?

Ans. $X_1 = 116.6$ ohms; $X_2 = 131.4$ ohms.

Locating Grounds. In case a line wire is grounded at some unknown point, the above method may be used in locating the ground. The grounded wire and a second wire free from grounds may be looped together and their combined resistance measured. The loop, as before, is connected as two arms of a bridge, but the junction is left insulated. X_1 is now the resistance from the testing station to the point where the wire is grounded. X_2 is the combined resistance of the rest of that wire and the whole of the other wire. The resistance to the grounded point is then

$$X_1 = R \frac{R_1}{R_1 + R_2}$$

As a rule the resistance of every line is part of the office data, and therefore $R = X_1 + X_2$ is known in advance and need not be remeasured. As the resistance per mile is also usually part of the office data, the actual distance corresponding to X_1 may be computed and a lineman sent to the point to make the repair. If in a severe storm several grounds occur on the same wire, this method, of course, cannot be used to locate the trouble. In the case of ocean cables this method is used with excellent results. The cable repair steamer can be sent to the point of trouble where the cable is raised and repaired.

Locating Faults. This method may be used in the care of a broken submarine cable if both ends are exposed to the water, but it cannot be used for broken land-lines because the ends, even if both on the ground, are too imperfectly grounded. If the conductor of a submarine cable is broken but the insulation left intact, this method cannot be used. A method, however, in which the distributed capacity of the cable is measured in microfarads (see Capacity Measurements later) can be used to determine the location of the break. This latter method may also be used for a broken land-line where the end of the wire hangs free of the ground.

MEASUREMENT OF BATTERY RESISTANCE

Voltmeter Method. The following voltmeter method may be used to measure battery resistance. The battery of one or more cells is connected in circuit through a key K, with a known resistance R. The voltmeter of appropriate range is connected, as shown in Fig. 30, to the terminals of the battery. With the key K open, V_1—the e. m. f. of the battery—is measured. The key K is then closed and V_2—the reading of the voltmeter—is observed. By Ohm's law the current is $\frac{V_2}{R}$. A part of the battery's e. m. f., equal to $V_1 - V_2$, is now lost inside the battery because of the resistance X of the battery. We then have the relation,

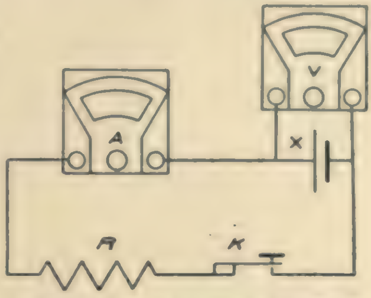

Fig. 30. Voltmeter Method of Measuring Battery Resistance.

$$V_1 - V_2 = X\frac{V_2}{R}, \text{ and}$$

$$X = R\frac{V_1 - V_2}{V_2}$$

If the resistance R is not known, an ammeter may be introduced into the circuit in series with R, and the current I measured directly. Then

$$XI = V_1 - V_2, \text{ and}$$

$$X = \frac{V_1 - V_2}{I}$$

It will be noticed that it is tacitly assumed that when the key K is open, not enough current will pass through the voltmeter to introduce any error. If the battery resistance is large this error is not negligible and a sensitive high resistance galvanometer with considerable additional resistance, perhaps 100,000 ohms besides, may be substituted for the voltmeter. If the deflections of the galvanometer in the two cases (open and closed) are d_1 and d_2, we then have

$$X = R\frac{d_1 - d_2}{d_2}$$

As the battery when furnishing a current begins at once to fall off in e. m. f., that is, *polarize*, a small error due to polarization makes the battery resistance appear too high. Such a value of the resistance R should be chosen as to make the deflections materially different. Otherwise a slight error in V_1 and V_2 or d_1 and d_2 will make their difference $V_1 - V_2$ or $d_1 - d_2$ many per cent in error.

Example. A cell has an e. m. f., $V_1 = 1.47$ volts when S is open and 1.12 when S is closed. R is 5 ohms. What is X?

Ans. $X = 1.56$ ohms.

Mance's Method. Another method is Mance's method, in which the battery, whose resistance X is to be determined, forms one arm of a Wheatstone's bridge, as indicated in Fig. 31. No key is placed in the galvanometer branch and no additional resistance, in the branch which includes the key S. The resistance in R_3 is adjusted until the galvanometer does not change its deflection on closing the key S. It is usually necessary to put considerable additional resistance R in the galvanometer arm to keep the deflection small. If the deflection does not change on closing the key S, it is evident that the decrease in the potential difference at the terminals of the cell due to its increased current when S is closed, must exactly equal the decrease in the potential difference between the terminals of R_3 due to this path being robbed of a part of its current because of the new path. Otherwise the potential difference at the galvanometer terminals, which is the difference of the potential differences over the two arms, would change and the deflection change. Similar reasoning applies to R_1 and R_2, only here the difference over R_2 increases by just the amount that that over R_1 falls, thus keeping the total amount constant for the combination of R_1 and R_2. The arrows show the direction of the currents in the various arms. If no change in the galvanometer current occurs, the changes in R_1 and R_3 must be equal and so also the changes in R_2 and X. It follows then if the galvanometer deflection remains constant whether S is open or closed, that

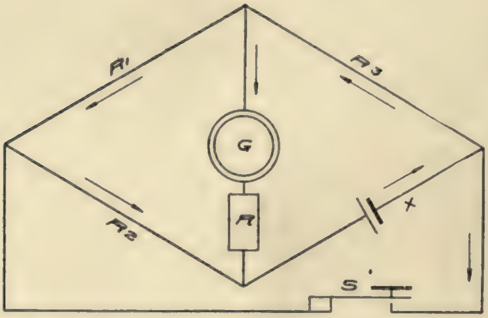

Fig. 31. Bridge Diagram for Mance's Method.

$$R_1 : R_2 :: R_3 : X, \text{ or}$$
$$X = \frac{R_2 \times R_3}{R_1}$$

Should the battery polarization change on closing the key S, the galvanometer deflection will change. For this reason the key S should be closed for an instant only.

Besides these methods there are excellent methods in which alternating currents are used, but they are too advanced to be described in this course. Such alternating-current methods should be used in measurement of the resistance of solutions (so called electrolytes) which are decomposed by a direct current.

MEASUREMENT OF ELECTROMOTIVE FORCE

Voltmeter Method. The simplest method of measuring an electromotive force is by the use of a voltmeter which indicates directly the number of volts. A voltmeter of the proper range should be chosen. For very small e. m. f 's the millivoltmeter, usual range 1 to 300 millivolts, *i. e.*, 1 to 0.3 volt, may be used. For higher e. m. f.'s, voltmeters reading to 1.5, 15, 150, and 300 volts respectively, are made by the Weston Electrical Instrument Co. and others. A voltmeter

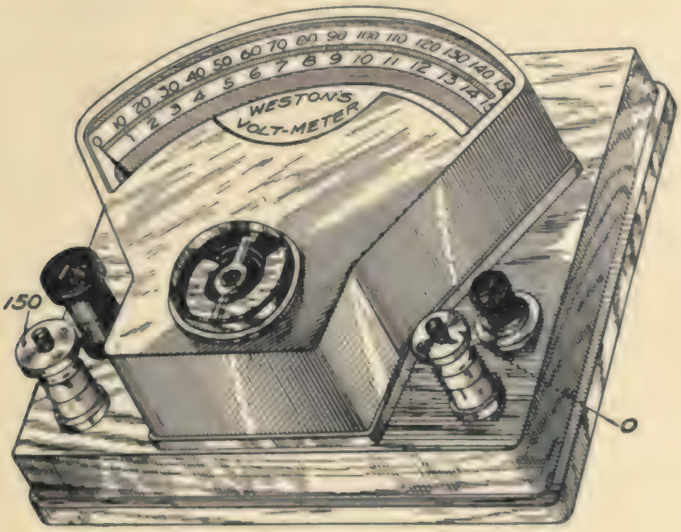

Fig. 82. Commercial Portable Voltmeter.

is simply a galvanometer calibrated to be read in volts. It is evident that if an additional resistance equal to that of the voltmeter is placed in series with the latter, twice the voltage will be required to produce the same deflection as before. In general, any resistance in series which makes the total resistance n times that of the voltmeter alone, may be used as a multiplier; and the reading of the voltmeter must be multiplied by n to get the value of the e. m. f. Such a multiplier may be bought with a voltmeter in order to make its effective range greater. For example, if the resistance of a voltmeter of range 0 to 150 volts, is 15,000 ohms, a multiplier having a resistance of 60,000 ohms will bring the total up to 75,000 ohms, and the constant n of the multiplier is 5. With this multiplier in the circuit the upper limit of the voltmeter is extended to 750 volts. If the multiplier is mounted inside the voltmeter, and if on using the binding posts marked 0 and 15 the range is 0 to 15 volts, and using the binding posts marked 0 and 150 the range is 0 to 150 volts, the multiplier evidently must have nine times the resistance of the main part. Such a voltmeter, shown in Fig. 32, is said to be a two-scale voltmeter, and it may be used equally well on either range. As the extra expense of providing the multiplier and extra binding post is slight, a two-scale voltmeter is a very inexpensive substitute for two voltmeters. It is also evident that a low range voltmeter may be used in connection with any resistance box as a multiplier. The Weston voltmeters have approximately 100 ohms resistance per volt of range and, therefore, take a maximum of about 0.01 amperes when used on an e. m. f. which is the maximum of the range. As a rule the current taken by a voltmeter is negligible in comparison with the current in the rest of the circuit.

The voltmeter method may be used equally well with both direct and alternating electromotive forces.

Potentiometer Method. For the comparison of e. m. f.'s, the potentiometer is the most accurate apparatus. When a balance is reached the e. m. f.'s to be compared are not allowed to furnish any current, and consequently no polarization results in their source. The effect of internal resistance is absolutely *nil* also. The arrangement of apparatus is shown in Fig. 33.

Two resistance boxes M and N, each of 10,000 ohms capacity, are arranged to have plugs withdrawn to a total of 10,000 ohms, and are connected in series with a battery B. To avoid injuring B, plugs corresponding to 10,000 ohms should be withdrawn before connecting it in circuit. The circuit has a high resistance and the effect of polarization of the battery B quickly reaches its limit and a steady current I flows through the circuit. If the resistance in box M is R ohms, that in box N is (10,000 − R) ohms; and the fall of potential over M is $R\ I$ volts, and over the box N is (10,000 − R) I volts. One of the cells to be compared, a standard cell of e. m. f. S, is connected in series with some high resistance A, a sensitive galvanometer G, and a key K. In general, on closing the key K the galvanometer will deflect; but if the resistances in M and N are adjusted until the potential difference over M is exactly equal to the e. m. f. of the cell S, the latter is in perfect balance and can neither supply current to the general circuit supplied by B nor can current be forced backward through the cell S. In that case the e. m. f. of S equals the fall of potential through M, and, calling R_1 the resistance in M,

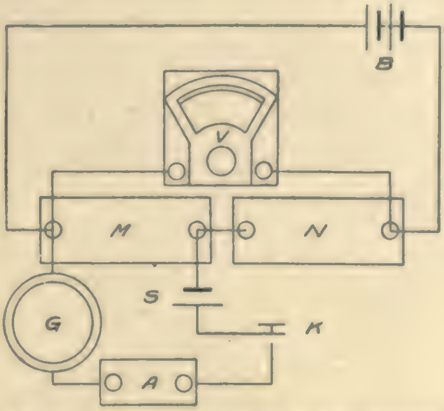

Fig. 33. Potentiometer Method of Measurement of E. M. F.

$$S = I\ R_1$$

If now a second cell of unknown e. m. f. X is substitued for S, and the resistances in M and N readjusted—but their sum kept 10,000—until on closing the key K no deflection results, calling the new value of the resistance in M, R_2, we have the relation

$$X = I\ R_2$$

It follows that

$$X = S\ \frac{R_2}{R_1}$$

If S is known, X may be computed. It is well to repeat the balance with S to be quite sure that no change has meanwhile occurred in the main battery B. Precaution should be taken in setting up the apparatus that B is greater than either S or X and that they are connected into the circuit so that they are in opposition to B. If these conditions are not obeyed, it is evident that no balance can be obtained. If no exact balance can be obtained, but a change of one ohm changes the galvanometer deflection from up to down the scale, the fraction of an ohm needed for an exact balance can be obtained by interpolation. In the next article on the calibration of a voltmeter such an interpolation is made.

Example. With a total resistance in M and N of 10,000 ohms of which the resistance in M was $R_1 = 5{,}267$ ohms, when the standard Clark cell of 1.433 volts was in the galvanometer circuit, and the resistance was $R_2 = 5{,}470$ ohms when the Leclanché cell was in the galvanometer circuit, what is the e. m. f. X of the Leclanché cell?

Ans. $X = 1.4882$ volts.

Calibration of a Voltmeter. If during the previous experiment, a voltmeter had been connected for the whole time between the extreme terminals of M and N, the potential difference V between the terminals of the voltmeter would have been

$$V = 10{,}000\,I = 10{,}000\,\frac{S}{R_1}$$

This gives a convenient method of calibrating a voltmeter by means of a standard cell of known e. m. f. S. The calibration may be extended to various points of the voltmeter by changing the e. m. f. of the main battery B. In such cases the resistance in M, to obtain a balance, will change in the inverse ratio. It is evident that the calibration cannot by this method be extended to points below the e. m. f. of the standard cell. In the case of high e. m. f.'s, it is desirable to increase the total resistance in M and N beyond 10,000 ohms. For example, if the e. m. f. produced by B at the terminals of the voltmeter is 150 volts, a total resistance of 100,000 ohms would be about right. In this case over 99,000 ohms would be in N and less than 1,000 in M. If several standard cells are available, they may be connected in series in the galvanometer branch, thus increasing the resistance for a balance in the box M. As most boxes have one ohm for their smallest resistance, a greater per cent of accuracy is obtained if the resistance in M is large. If an exact balance cannot be obtained and the nearest smaller resistance produces a deflection d_1 one way, and the nearest larger resistance produces a deflection d_2 in the opposite direction, the fraction of an ohm which would have produced a balance is evidently

$$\frac{d_1}{d_1 + d_2}$$

Example. With a total resistance of 100,000 ohms in M and N, and 987 ohms in M producing a deflection of 5 divisions down the scale, and 988 ohms producing a deflection of 15 divisions up the scale, and a standard Clark cell of 1.433 volts e. m. f. in the galvanometer circuit, what is the correction to be added to the voltmeter reading which was 144.9 volts? Ans. Correction = + 0.25 volt.

Suggestion of Solution. The change in deflection by change of one ohm is 5 + 15 scale divisions; therefore, 987 is 0.25 ohm too small and 988 is 0.75 ohm too large. The e. m. f. figures out 145.15 volts; therefore, 0.25 volt will be added to the voltmeter reading to give the correct result.

This method, as will be seen later under the head of "Measurement of Current," can be used with a standard cell to measure a current.

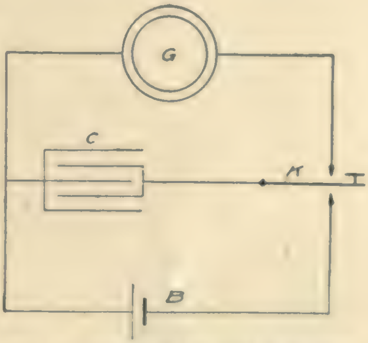

Fig. 34. Condenser Method of Measurement of E. M. F.

Condenser Method. If a condenser of capacity C is connected by means of a charge and discharge key K, which has an upper and a lower contact, as shown in Fig. 34, alternately to a standard cell of e. m. f. B, and a ballistic galvanometer G, the throw d of the galvanometer will be a measure of the charge of the condenser equal to $B \times C$. If, now, a cell of unknown e. m. f. X is substituted for B, the deflection d_2 will be a measure of the charge of the condenser now equal to $X \times C$. It follows that

$$X = B \frac{d_2}{d_1}$$

This method is free from difficulties due to polarization and internal resistance of the cells; because the very small charge taken by the condenser produces no measurable polarization, and the effect of internal resistance is only to lengthen the time of charging of the condenser, but not to change the total quantity.

The accuracy of the method, however, is limited to that of the reading of the deflections d_1 and d_2, and it is difficult to get results much closer than, say, $\frac{1}{5}$ of 1%. The potentiometer method will give results easily to $\frac{1}{100}$ of 1% if the resistances used are accurate; and in general the accuracy of the potentiometer method is limited only by the accuracy of the resistances. For accurate comparisons the potentiometer method is always used.

VOLTAIC CELLS AND BATTERIES

A *voltaic cell* is usually composed of a pair of electrodes immersed in a liquid or in two liquids separated from one another by a porous partition. The liquid, or liquids, must be what is known as an *electrolyte;* and must undergo a chemical breaking up, called *electrolysis,* with chemical action on one or both electrodes when the circuit is closed and a current flows through the cell.

Some cells fall rapidly in e. m. f. when the circuit is kept closed. This phenomenon is known as *polarization,* and it frequently is due in large part to the deposit of a film of hydrogen gas on the surface of one of the electrodes (the cathode). This gas is one of the products of the electrolysis of the liquid. If the cathode, for example a copper plate, as in the case of the gravity cell, is surrounded by a solution of copper sulphate, the hydrogen does not reach the copper plate but is intercepted by the copper sulphate solution, and copper instead of hydrogen is deposited. Naturally, the deposit of copper on a copper plate produces no polarization. The copper sulphate solution is called a *depolarizer.* The other electrode of the gravity cell is zinc and is immersed in a dilute solution of either zinc sulphate or sulphuric acid.

In the *Grove* and the *Bunsen* cells, the depolarizer is nitric acid in a porous cup in which the cathode is immersed. The nitric acid is rich in oxygen which it gives up to oxidize the hydrogen gas, thus forming water (H_2O) which makes the solution more dilute but causes no polarization. Cells with liquid depolarizers cannot be left on open circuit as the liquids diffuse into one another and the cell is spoiled. Cells for open circuit use must have either a solid or a paste for a depolarizer. The Leclanché cell has manganese dioxide (a solid) packed in a porous cup about its cathode of carbon. The data of various cells can be found in books on cells.

Standard Cells. There have been various cells used as standards of e. m. f. of which the *Clark* and the *Weston* have received most attention. A *standard cell* must be composed of materials which, while the cell is in use, do not change; that is, no new substance may be formed by the action of the cell; the cell should have little or no polarization when used by zero methods like the potentiometer method described above; the cell also must not deteriorate when left on open circuit.

Both the Clark and the Weston cells fulfill these requirements. At the International Electrical Congress, held in Chicago, 1893, the normal Clark cell was recommended for international legalization and its e. m. f. at 15° C. was voted to be considered for practical purposes as 1.434 volts; and a committee, consisting of Professors von Helmholtz, Ayrton, and Carhart, was charged with the duty of drawing up specifications for the precise form of the cell. Von Helmholtz died soon afterward and the other members of the committee could not agree on the specifications, with the result that the principal countries (in electrical matters) have never agreed on a form for the cell.

It has now been displaced by the Weston cell, which, in 1908, was recommended by an International Conference in London as an international standard. It is now known that the Clark cell has an e. m. f. slightly below 1.433 volts, instead of 1.434 volts as thought in 1893. The normal Clark cell uses as materials zinc amalgam in a saturated aqueous solution of zinc sulphate, with an excess of zinc sulphate crystals present, and pure mercury in the presence of mercurous sulphate in the form of a paste which acts as the depolarizer. The action of the cell is to form more zinc sulphate and reduce some of the mercurous sulphate to mercury, or *vice versâ*, when the current flows in the direction of the e. m. f. or is driven in the opposite direction by a greater outside e. m. f. The principal objection to the normal Clark cell is that its e. m. f. changes by a considerable amount with change in temperature, falling about 0.08% for every Centigrade degree rise in temperature.

The Weston normal cell is similar to the Clark cell except that cadmium replaces the zinc, and cadmium sulphate the zinc sulphate The Weston normal cell has a much lower temperature coefficient than the Clark cell, its e. m. f. falling about 0.00406% for each Centigrade degree rise above 20° C. and *vice versâ*. The e. m. f. of the

Weston normal cell at 20° C. was recommended by the London conference of 1908 to be taken provisionally as 1.0184 volts.

Storage Cells. Many voltaic cells when exhausted, may be recharged by forcing current through the cell in the reverse direction by the application of an outside e. m. f. greater than the e. m. f. of the cell. Such cells are called *storage cells.* In general only such cells as form no *new* kind of material when discharging are reversible, and evidently a cell to be charged and discharged repeatedly must be reversible.

All standard cells must be reversible. Reversibility, however, is not the only requirement of storage cells to be used commercially. Other qualities required are low internal resistance, large capacity for charge measured in ampere hours in comparison with size and weight, long life under service, ability to stand without harm in open circuit, moderate cost, etc.

The storage cell most used commercially has both plates of lead with dilute sulphuric acid as electrolyte and lead peroxide as the depolarizer. The lead peroxide is a solid or paste which adheres to the positive pole of the battery. The e. m. f. of a lead cell is about 2.2 volts when fully charged and may safely be discharged until its e. m. f. is reduced to 1.8 volts. When the cell is charged one plate has a deposit of lead peroxide, and the other has a spongy texture, due to its reduction from an oxide or a sulphate of lead in its previous history. When the battery is discharged, the sulphuric acid is electrolyzed; the hydrogen formed reduces some of the lead peroxide of the positive, and the sulphion forms some insoluble lead sulphate from the negative. The sulphuric acid becomes more dilute. On recharging the cell the lead sulphate is reduced to spongy lead at the negative, some additional lead peroxide is formed on the positive, and the density of the sulphuric acid increases. For details as to the manufacture of the various varieties of lead cells and other storage cells, the reader is referred to works on storage cells.

To increase the capacity of a cell the negative consists generally of a number of plates connected together both electrically and mechanically, and the positive consists of one plate less in number and connected together in the same manner. The positive plates are interlarded between the negative plates.

Storage cells are also called *secondary cells* or *accumulators* by some writers.

Batteries. The word battery is technically used to mean a group of cells. In common parlance the word is used sometimes to mean a single cell; but this use is not to be recommended.

MEASUREMENT OF CURRENT

Electrodynamometers. In the choice of a unit of current, it was decided that a unit of current in a straight conductor at right angles to a unit magnetic field, should exert a force (at right angles to both the directions of current and field) of one dyne per unit length of the conductor. As mentioned earlier, this unit of current was thought to be inconveniently large by the committee of the British Association for the Advancement of Science, which had the matter of electrical units in charge, and as a consequence for practical purposes they recommended that one-tenth of this theoretical unit should be taken as the practical unit. The latter unit is called the *ampere*. As the magnetic field due to the flow of an electric current in coils, may be computed from the data of the coils and the current, it is evident that absolute electrodynamometers may be made to measure current without the intervention of other electrical measuring apparatus. These absolute electrodynamometers may take various forms, including that of current balance. By means of an absolute electrodynamometer and a standard resistance, the e. m. f. of standard cells may be determined with a high degree of accuracy according to the principle of Ohm's law.

By comparison either directly with the standard electrodynamometer or indirectly by means of standard resistances and standard cells, other forms of electrodynamometers and all forms of ammeters may be adjusted so as to read amperes. It is evident from the above that as more improved absolute electrodynamometers are constructed, we may expect greater exactness in the determination of the e. m. f. of the Weston normal cell, which for the present is taken as 1.0184 volts at 20° C.

Ammeters. An ammeter is a galvanometer graduated so that it reads current directly in amperes. This graduation is obtained directly by comparison with either an absolute electrodynamometer or indirectly by means of a standard cell and standard resistances.

Ammeters for any desired range of current are on the market, and the accuracy of their readings is in proportion to the care with which they have been constructed and calibrated. Even the best are moderate in price and the poorest should not be one per cent in error.

Ammeters to measure large currents carry the main portion of the current through shunts which differ theoretically in no respect from the shunts used with other forms of galvanometer.

To measure current by means of an ammeter involves introducing the instrument into the circuit, care being taken to connect the terminal marked + to the positive terminal of the source of e. m. f. The exact position of the ammeter in an undivided circuit is not important, as the current is the same throughout the circuit. Care should be taken that the ammeter has a range which the current does not exceed; otherwise the pointer may be bent or even the ammeter may be burned out by the action of excessive current. An ammeter has an exceedingly small resistance, and to connect an ammeter without additional resistance between the terminals of a dynamo or a battery is to produce a short circuit practically. Excessive current will flow through the ammeter and it probably will be destroyed.

Ammeters designed for direct-current circuits cannot be used on alternating-current circuits. Some forms of A. C. ammeters may be used on D. C. circuits; but as a rule ammeters should be used on the type of circuit for which they are designed.

Calibration of Ammeters. An ammeter may be compared directly with another in the same circuit by putting them in series and observing their readings with various values of the current. The current may be varied by changing the resistance in the circuit or the e. m. f. The potentiometer method may be used to calibrate an ammeter.

Potentiometer Method. The most exact method of measuring a current, assuming that the e. m. f. of a standard cell and the resistance of standard coils are known, is the potentiometer method. This is not an *absolute* method. The arrangement of the apparatus is somewhat complicated; but if it is compared with the potentiometer method as used for the comparison of e. m. f.'s (page 41) it will be seen that the commutator C, Fig. 35, is used to insert in the galvanometer branch either the standard cell of known e. m. f. S or a potential difference over a known resistance R due to the

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current to be measured *I*. The current *I* may be passed also through an ammeter *A* in circuit with *R*, a rheostat and an auxiliary battery B_2 which causes the current *I* to flow through the circuit. In the lower part of the diagram the galvanometer *G* and, if desired, a high resistance to protect the galvanometer, are connected between the left end of the commutator and one terminal of the resistance box *L;* the right end of the commutator is connected to the other terminal of *L*. The auxiliary battery B_1 serves to send a constant current through *L* and *M*, whose combined resistance is kept constant at, say, 10,000 ohms. In setting up the apparatus, 10,000 ohms should be inserted in *L* and *M* before connecting the battery B_1; otherwise the battery will become badly polarized due to an excessive current. This precaution is very important. When a balance is obtained no current passes through the galvanometer on closing the key *K*.

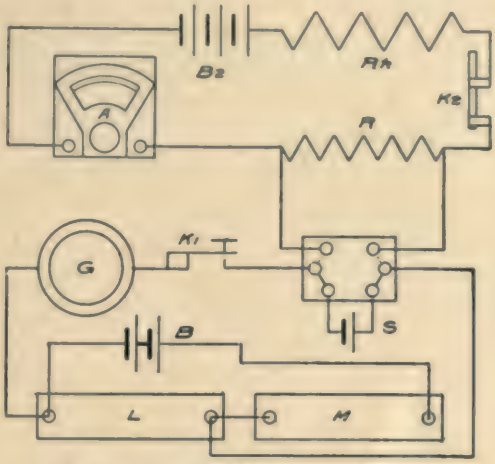


Fig. 35. Potentiometer Method of Current Measurement.

The order of procedure is as follows: first, connect *S* in circuit by means of the commutator *C* and shift resistance from *L* to *M*, or *vice versâ* until, on closing the key *K* a balance is reached, as indicated by a zero deflection of the galvanometer. The fall of potential through *L*, which under these conditions is exactly equal to the e. m. f. of the standard cell *S*, is then equal to its resistance R_1 multiplied by the current *I* from the battery B_1, or $S = R_1 I_1$; second, close the upper circuit by K_2, reverse the commutator to the position shown in the figure by dotted lines, which throws the p. d. over *R* into the galvanometer circuit. Adjust *L* and *M* until no current flows through the galvanometer on closing the key K_1. The total resistance in *L* and *M* is still kept 10,000 ohms. The resistance in *L* now has a value R_2, and the potential difference over *L* is now $R_2 I_1$ and is also in the galvanometer circuit. If no current flows through the galvanometer, $R_2 I_1$ must exactly equal and oppose the fall of potential $R I$ over the resistance R. We then have

$$S = R_1 I_1, \quad \text{and } R I = R_2 I_1,$$

or, combining these equations,

$$I = \frac{R_2 \times S}{R \times R_1}$$

By adjusting the rheostat in the upper, or the battery B_2 circuit, the current to be measured I, and consequently the point at which the calibration of the ammeter is desired, may be changed at will. The only limitation is that the battery B_1 must have a higher e. m. f. than the standard cell's e. m. f., and also higher than the largest p. d. over the resistance R.

As the e. m. f. of B_1 may be increased, if necessary, by introducing additional cells into B_1, there is no limit to the current I (in the upper circuit) which may be measured. In the case of very large currents the standard resistance R should be of relatively low resistance. If too much heat is developed in R its temperature may rise with consequent change of resistance.

Standard resistances are made of manganin which will carry any reasonable current without undue heating or change of resistance. These standards are arranged so that the wire may be immersed in an oil bath (pure petroleum) which may be kept stirred so that the heat may be carried away. A thermometer in the oil bath may be used to measure the temperature. Allowance thus may be made for any change in resistance due to change in temperature.

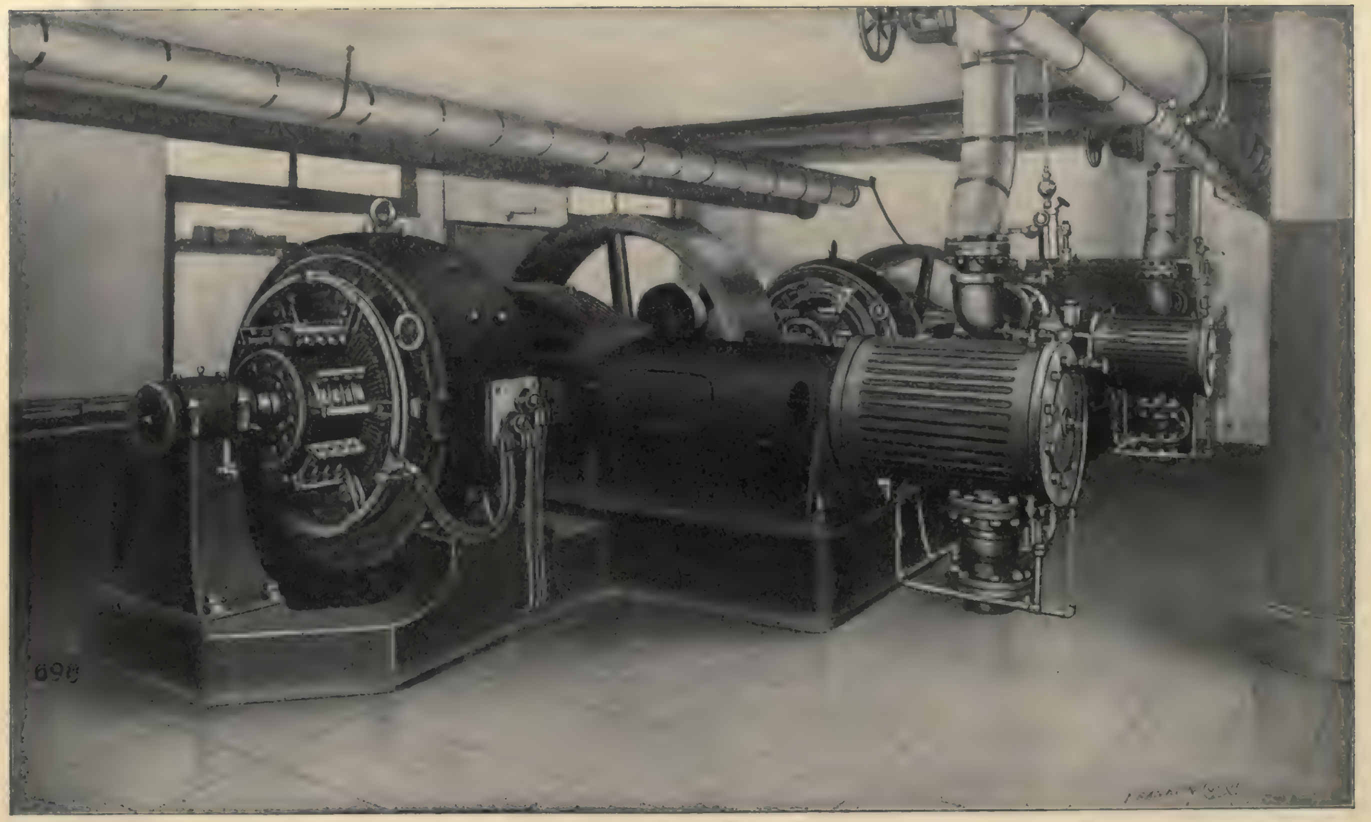
Such standards are made by the best manufacturers for 100, 10, 1, 0.1, 0.01, and 0.001 ohms resistance. Standard resistances calibrated by the Bureau of Standards at Washington are moderately expensive, but the cost is not higher than the cost of manufacture and testing at the Bureau would warrant. The certificate which accompanies each coil states the resistance at 20° C. and the change of resistance per degree change of temperature.

Silver Voltameter Method. If a current is passed through a solution of silver nitrate, each ampere deposits 0.001118 gram of silver from the solution each second. This is closely equal to $4\frac{1}{40}$ grams per hour. The silver voltameter is very difficult to handle with the degree of accuracy that is necessary for good results, so it is not recommended for general use.

To set up a voltameter, a platinum bowl is used as a cathode and a plate of pure silver as an anode. The electrolyte, 15 to 20 parts by weight of pure silver nitrate added to 100 parts of distilled water, is placed in the bowl, and the anode immersed in the solution. A current density of $\frac{1}{5}$ ampere or less per sq. cm. is allowed at the anode, and of $\frac{1}{50}$ ampere or less per sq. cm. at the cathode. Care is to be taken that no particles of silver mechanically detached from the anode shall reach the cathode. This may be accomplished by wrapping the anode in clean filter paper.

Before weighing the cathode to determine its increase in weight, any trace of the solution must be removed by careful working with distilled water and the cathode dried. This seems easy, but it is difficult, in fact.

The solution should be made anew for each experiment.



TWO 60 K. W. ENGINE TYPE GENERATORS DIRECT CONNECTED TO BALL ENGINES

Northern Electric Manufacturing Co.

ELECTRICAL MEASUREMENTS

PART II—ADVANCED

MEASUREMENT OF CAPACITY

Ballistic Galvanometer. In the measurement of the capacity of a condenser by the methods given in the subsequent pages, the charge of electricity from the condenser is allowed to flow as a momentary current through a galvanometer, giving the suspension a sudden *kick*. In order to calculate from this deflection the *quantity of electricity* in the condenser, it is necessary to assume that the galvanometer suspension is so heavy that it will not have moved very far before the charge has completely passed. This requisite, viz, a heavy suspension, is the distinguishing feature of the *ballistic* type of galvanometer. (See Fig. 7, Part I.)

As a rule the methods of measurement involve only a comparison of the deflections produced in the ballistic galvanometer by charged condensers of known and unknown capacity, so that, as long as the capacity of a standard condenser is known, the unknown factors, the galvanometer constant, etc., are unimportant. Nevertheless it may be instructive to know how these unknowns can be determined and the deflections can be made to give the actual quantity of electricity in the given condensers.

Because of the fact that the deflection of the galvanometer is not proportional to the current which produces the deflection, it is necessary to know the factor called the *constant* of the galvanometer before measurements can be taken. This constant is used in various forms but can be briefly stated as *the constant ratio between the current and the deflection produced by it.* When put in more definite form it can be given as follows:

$$K = \frac{2\,I\,D}{d}$$

in which I is the current flowing in the galvanometer, D is the distance

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from the galvanometer mirror to the scale, and d is the deflection produced on the scale.

With this in mind let us consider *how to find the quantity of electricity Q from the throw θ of the galvanometer, the galvanometer contant K, and the half period of the suspension.*

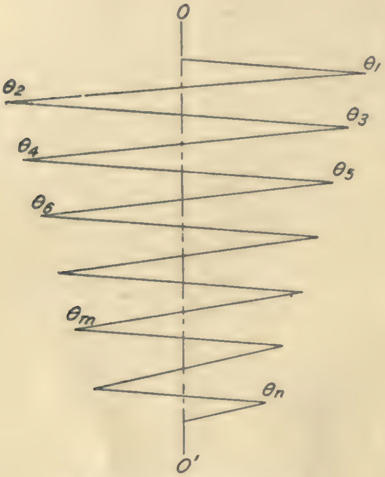


Fig. 36. Damping Diagram.

As has been stated above, while the quantity Q is passing through the galvanometer, short though it may be in duration, it constitutes a current and the magnetic effect of this current exerts a turning moment on the coil.

If I represents the mean value of this current, then the mean moment of force $\overline{Fh}$ acting on the coil while the current is flowing is

$$\overline{Fh} = I\,\mathrm{H}\,A$$

in which H is the strength of the field and A is the area of the galvanometer coil. If τ is the duration of the discharge, then the moment of force times the time can be given by

$$\overline{Fh}\tau = I\tau\mathrm{H}A = Q\mathrm{H}A$$

in which Q is the quantity of electricity, equal to $I\tau$.

If the moment of inertia M of the suspension and the angular velocity, which is given to it by this *kick*, are taken into consideration, the quantity of electricity Q may be obtained from the above equation as follows:

$$Q = K\omega\frac{M}{T_o}$$

in which ω is the angular velocity and T_o is the torsion constant of the suspension. By taking the half period of the suspension, which is easily obtained by counting the time of a given number of swings, and expressing ω in terms of the angle of throw θ, the expression for the quantity of electricity is given by the following equation:

$$Q = \frac{K\theta t}{\pi}$$

in which K is the galvanometer constant, θ the angle of throw (obtained by dividing the deflection d by twice the distance from mirror to scale D), t the half period of the suspension, and π 3.1416.

For accurate work θ must be multiplied by a damping factor $1/\rho$, derived as follows: With the suspension swinging freely, Fig. 36, take a deflection θ_m, then after a given number of swings $(n\text{-}m)$ take another deflection, θ_n; ρ is the $(n\text{-}m)$ root of the ratio $\frac{\theta_m}{\theta_n}$.

Condensers. A condenser consists in its simplest form of two metal sheets separated by a nonconducting material, Fig. 37. If an e. m .f. is applied to the two metal sheets, they will take a static charge, one positive and the other negative. The nonconducting material is called a *dielectric*, as the electric force acts through it (*dia* meaning through). The capacity of such a condenser is proportional to the area of the sheets and inversely proportional to the thickness of the dielectric. If the condenser is in the form of a glass jar coated outside and inside with tin foil, the arrangement is called a *Leyden jar*. A considerable portion of the surface near the edges of the jar should be free from the tin foil coating in order that the charge may not leak over the surface of the glass. The best condensers are made of many sheets of mica with sheets of tin foil interlarded, every alternate one being connected to one, and the others to the other terminal of the condenser, Fig. 38. By using many sheets of tin foil the capacity is increased in proportion to the total area. Mica is an excellent material for the dielectric as its resistance is extremely high, and very thin sheets have enough strength to withstand the mechanical stress

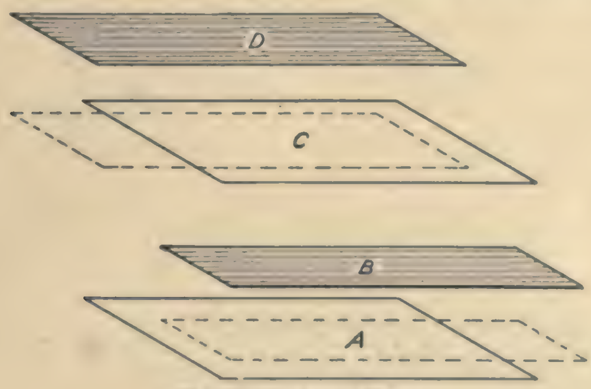


Fig. 37. Condenser Sheets.

due to the electric charges without breaking down. The mica and tin foil are clamped in place and the whole immersed in melted paraffin and then withdrawn, carrying out a coating of paraffin which protects the condenser from the effects of moisture. Several condensers of assorted capacities are frequently mounted in one box, Fig. 39. A 1 m. f. box will frequently have condensers of 0.5, 0.2, 0.1, 0.1, 0.05 and 0.05 microfarad, Fig. 40. Cheaper condensers have paraffined paper or other materials in place of mica; but are usually poor since the dielectric, though it does not break down, is apt to yield gradually to the strain of the charge, producing an effect which is known as *absorption of the charge.* It seems as though some of the charge had been lost for when the condenser is discharged, less charge comes out than was put in. It is true that real leakage causes a loss of part of the charge, but we find also that a poor condenser, if set aside after being discharged, will, on a later test, show a small charge which has come from the gradual return of the dielectric to its original state. The Leyden jar (glass dielectric) absorbs a considerable portion of its charge. Standard condensers are sometimes made with massive plates of metal and with air, which has no absorption, as the dielectric. They are very expensive and have small capacity. For practical purposes

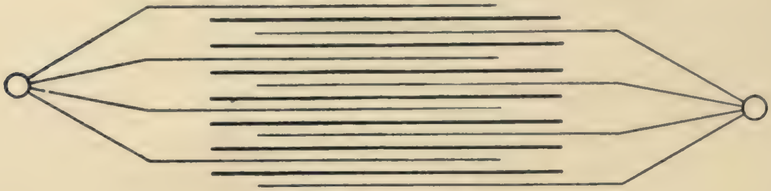


Fig. 38. Simple Condenser.

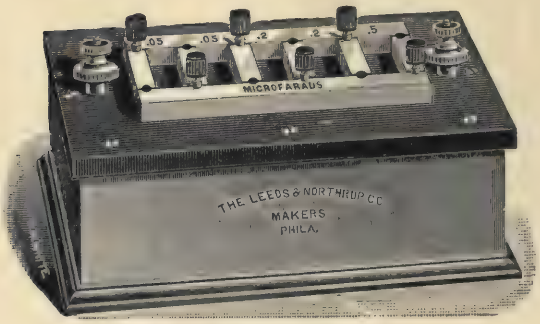


Fig. 39. Variable Condenser.

the best condensers have mica for the dielectric, for mica shows almost no absorption of the charge.

Single conductor submarine and land cables have the properties of condensers, the water acting as the second sheet in the case of the former, and the usual lead covering in the case of the latter. In telephone cables, each pair of wires and the insulation between make up a condenser. These cables almost always show considerable absorption of the charge.

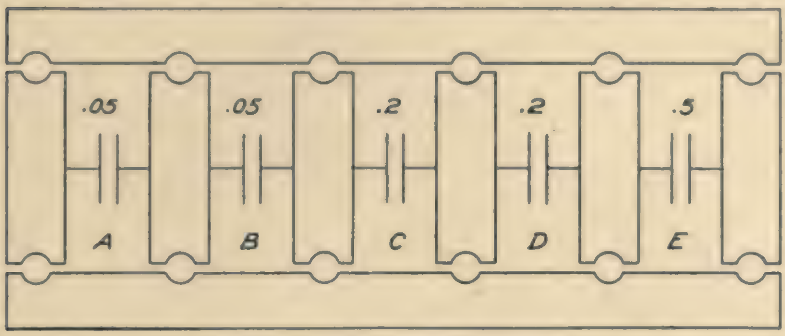


Fig. 40. Plan of Variable Condenser.

Direct Deflection Method. Two condensers may be compared as to their capacity, if first one and then the other is charged by a cell B of known e. m. f., and then discharged through a ballistic galvanometer G, Fig. 41. If the deflection with the standard of capacity C is D_1, and that with the unknown of capacity X is d_2 then

$$X = C\frac{d_2}{d_1}$$

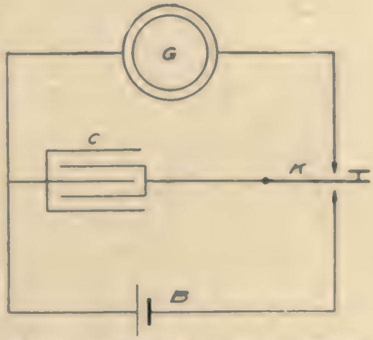


Fig. 41. Diagram for Direct Deflection Method.

A charge and discharge key K, Fig. 42, connects the condenser first to the battery and then to the galvanometer.

This method is convenient, but the accuracy of the results depends on the accuracy with which the throw of the galvanometer can be read. The accuracy is not much better than 1% even if neither condenser shows absorption of charge. If either condenser absorbs charge, the ratio of the deflections will depend on the time of charge and the slowness of clearing out of the charge. There are better methods.

Example. With a condenser of 0.5 microfarads in circuit, the deflection is 46 divisions; with the unknown capacity X in circuit, the deflection is 69 divisions. What is X?

Ans. $X = 0.75$ m. f.

Bridge Methods. The Wheatstone's bridge method of comparing resistances may be adapted to the comparison of two capacities. The apparatus may be arranged as shown in either Fig. 43 or Fig. 44. In the former a charge and discharge key is used to charge and discharge the condensers. If all the charge taken by C_1 passes through R_1 and all taken by C_2 passes through R_2, both in charging and discharging, then the galvanometer will not deflect; otherwise it will deflect in opposite directions for the charge and discharge. As the current divides in parallel circuits in inverse proportion to the resistances; and as the charge, and therefore the current, taken by condensers in parallel is directly proportional to their capacities, it is evident that if no current passes through the galvanometer

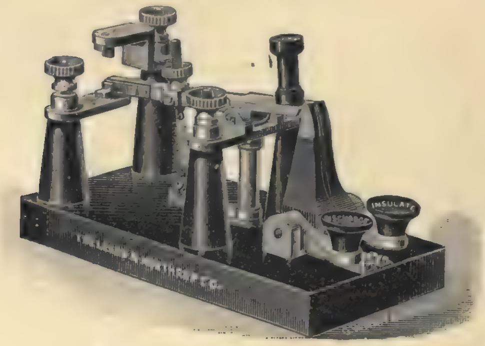


Fig. 42. Kempe Discharge Key.

$$C_1 : C_2 : : R_2 : R_1$$

therefore

$$C_1 = C_2 \frac{R_2}{R_1}$$

In Fig. 44 the battery circuit produces a current through R_1 and R_2, and they take potential differences between their terminals proportional to their resistances when the current becomes steady. The condensers will take a certain charge; and if the galvanometer is open, both condensers must take equal charges regardless of their capacities. If one has a smaller capacity than the other, the former will acquire a smaller potential difference than the latter, as the charge is equal to the product of the capacity and the potential difference. If C_1 and R_1 acquire equal potential differences, and C_2 and R_2 also equal potential differences, then on closing the galvanometer key no deflection will result. If on closing the galvanometer key a deflection results, it is evident that the above relation is not satisfied. If no deflection results

$$C_1 : C_2 : : R_2 : R_1,$$

and

$$C = C_2 \frac{R_2}{R_1}$$

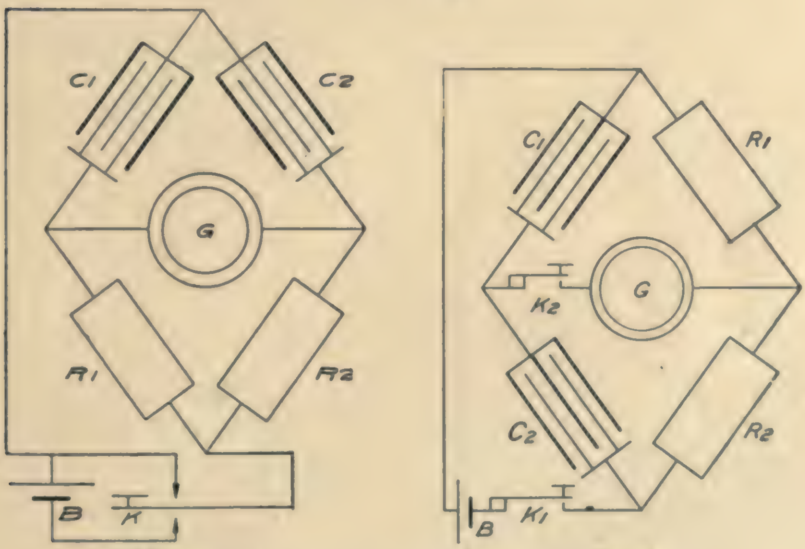


Fig. 43. Fig. 44.

Diagrams for Bridge Methods for Measuring Capacities of Condensers.

The order of closing and opening keys is important. It should be as follows: First close K_1, then K_2 and note deflection if any; second, open K_2, then K_1, then close K_2 and note deflection (or discharge) which should be in opposite direction. Then open K_2. It is necessary to discharge the condensers before recharging them, otherwise they will take no new charge beyond what is necessary to make up for leakage or absorption of charge. If the condensers absorb charges it is impossible to get a perfect balance.

Method of Mixtures. In the method of mixtures the positive charge taken by one condenser is mixed with the negative charge of the other, and *vice versâ*, and the remaining difference of charges is discharged through the galvanometer. This method allows the time of charge and the time of mixing the charges to be varied at will, thus allowing the absorbed charge more or less time to make itself felt.

In Fig. 45, the Pohl's commutator P, by bringing the points e and c and f and d into contact as indicated, allows the condenser C_1 to charge until its potential difference is equal to that over R_1 (due to the current from the battery B), and also allows C_2 to charge until its potential difference equals that over R_2. The commutator is then reversed, bringing e into contact with a, and f into contact with d. The points a and b are permanently connected together. The + charge on C_2 can mix with the − charge on C_1, and the other charges on C_1 and C_2—which were previously so-called *bound charges*—now become free and can mix also. The remaining charges are divided between the two condensers in proportion to their capacities. If now the key K is closed, these remaining charges are discharged through the galvanometer. If no deflection occurs the charge remaining must be *nil*. As the charge taken by a condenser is equal to the product of its capacity multiplied by its potential difference, and as the potential differences to which C_1 and C_2 were charged were proportional to R_1 and R_2, then, by Ohm's law, when the charges on C_1 and C_2 are equal we must have the relation that

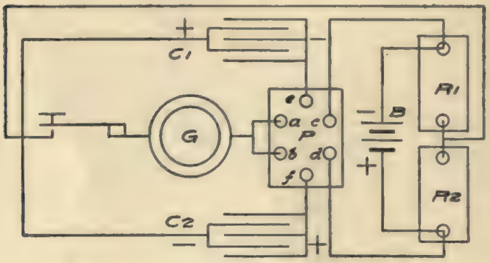


Fig. 45. Diagram for Method of Mixtures.

$$C_1 R_1 = C_2 R_2,$$

or

$$C_1 = C_2 \frac{R_2}{R_1}$$

If condenser C_1 absorbs part of its charge, its total charge will increase on charging for a longer time. If the charges are allowed to mix for a longer time there is more opportunity for the absorbed charge to be given up. It follows that if the time of charging is short, the capacity of the C_1 will appear to be smaller than if a longer time of charging were allowed. With good mica condensers little effect of absorption will be found. With most other dielectrics the absorption is quite marked.

Example. If in the bridge method or in the method of mixtures, $C_1 = 0.5$ microfarads, $R_1 = 2{,}340$ ohms, and $R_2 = 1{,}000$ ohms, what is C_2? Ans. $C_2 = 1.17$ microfarads.

Absolute Method. If a condenser is rapidly charged through a galvanometer and then discharged by short circuiting the condenser, the deflection of the galvanometer will be the same as though an equal charge had passed through the galvanometer in the form of a steady current during the same time. The difficulty with the method is that the galvanometer obstructs the complete charge of the condenser when the charges become very frequent. To get around this difficulty a second circuit to the galvanometer is arranged to carry a steady current equal in value but opposite in direction to the pulsating current due to the charge of the condenser. The result is that the galvanometer carries only the difference of these two currents, and when a balance is obtained, the resultant current is a small alternating current, alternately helped and hindered by the resistance and inductance of the galvanometer. The method then becomes somewhat like the Wheatstone's bridge method.

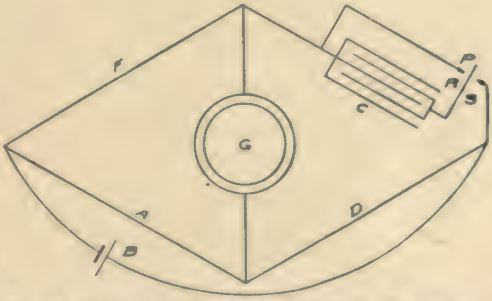


Fig. 46. Diagram for Absolute Method of Capacity Measurement.

To regulate the number of charges to a uniform number per second, a small motor running at a constant known speed or an electrically driven tuning fork of known frequency of vibration, may be used. The apparatus is arranged as in Fig. 46. If the condenser of capacity C is charged when the movable piece P makes contact with S, part of the charge will pass through the galvanometer of resistance G. The condenser is discharged when P makes contact with R. The battery B tends to send a steady current through the divided bridge circuit, part passing through F and G (both of fairly high resistance) and part through A (of low resistance). The resistance in the battery arm must be made very low in comparison with F, D, and G. Let us suppose D a fixed resistance, say, 1,000 ohms, and A, 1 ohm. In this case two proportional arms of a *postoffice* box may be used. Adjust F until a balance is obtained, with no deflection of the galvanometer. Let n be the number of charges of the condenser per second. We then have the closely approximate relation

$$C = \frac{A\ (F + G) \times 10^6}{n\,F\,(DG + DF + AG)}$$

The capacity C is in microfarads. If the factor 10^6 is omitted, the formula will give C in farads.

If the resistances in the battery branch and in A are not small, it is necessary to use a more complicated formula.

Example. When a balance is obtained $A = 1$ ohm, $F = 2{,}340$ ohms, $G = 10{,}000$ ohms, $D = 1{,}000$ ohms, and $n = 32$ periods per second. What is the capacity of C? Ans. $C = 0.01334$ microfarad.

Alternating-Current Method. If a circuit through which an alternating current is flowing includes a condenser, the charge and discharge of the condenser is repeated with every alternation of the current. The quantity of each charge is equal to the capacity multiplied by the p. d. to which the condenser is charged. The rate of charge or discharge is the value of the current at any particular instant. It is proved in treatises on alternating currents that the effective value of a current or an e. m. f. is the square root of the average square of its instantaneous values. Alternating-current ammeters and voltmeters such as those shown in Figs. 47, 52, and 53, calibrated with direct currents, show the effective values of A. C. currents and electromotive forces. The theory of alternating currents shows that the current passing in and out of a condenser, if the e. m. f. follows a sine law, is

$$I = \frac{2\,\pi\,n\,C\,E}{1{,}000{,}000}$$

From this it follows that

$$C = \frac{1{,}000{,}000\ I}{6.2832\ n\ E} = 159{,}155\ \frac{I}{n\,E},$$

when I is the effective value of the current in amperes, E the effective value of the e. m. f. in volts, n the number of cycles per second of the e. m. f. (and consequently of the current too), and C the capacity of the condenser in microfarads. If the capacity is rated in farads, omit the factor 1,000,000. In Fig. 48 the current I flows through the ammeter A, and the condenser of capacity C in series. A high resistance voltmeter V measures the potential difference E at the terminals of the condenser.

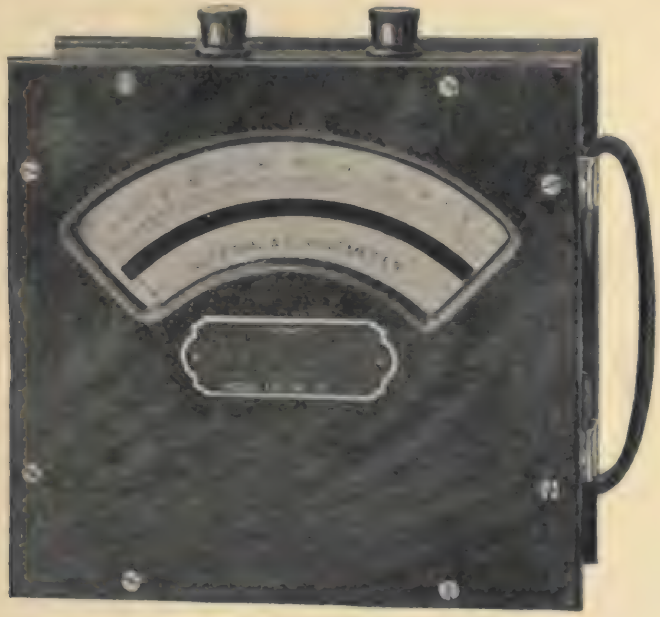


Fig. 47. Commercial Form of Portable A. C. Voltmeter.

Example. The ammeter reads 1 ampere, the voltmeter 220 volts, the frequency n is 60 cycles per second. What is the capacity of the condenser?

Ans. $C = 12.06$ microfarads.

If the voltmeter takes much current in proportion to the whole, a correction must be made for it. From the theory of alternating currents a condenser takes a current one-quarter of a period in phase *ahead* of its potential difference. A circuit in which there is both resistance and inductance takes a current lagging *behind* the potential difference. As voltmeters have some inductance, which should be small in comparison with the resistance, it will be seen that the current in the voltmeter lags a little over a quarter period in phase behind the condenser current. The relation of the currents with apparatus set up as in the previous figure is shown in Fig. 49, in which I_a, I_c, and I_v, are the currents in the ammeter, condenser, and voltmeter respectively. I_a and I_c are practically of equal length. The directions of the arrows show the phase relations.

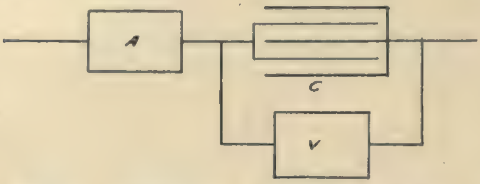


Fig. 48. Diagram for A. C. Method of Capacity Measurement.

If the condenser current is small and the voltmeter current large relatively, it will be seen from Fig. 50 that I_a may be materially larger than I_c, and that the ammeter reading must be corrected. It may be shown by trigonometry that if the voltmeter current lags by an angle a behind its potential difference, we will have

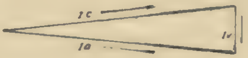


Fig. 49.

$$I_c = I_v \sin a + \sqrt{I_a^2 - (I_v \cos a)^2}$$

By the theory of alternating currents $\tan a = \frac{2 \pi n L}{R}$, where n is the frequency of the system, L the self-inductance, and R the resistance of the part of the circuit considered. If n, L, and R are known, a may be found.

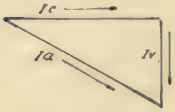


Fig. 50

Example. What correction, if any, should be made in the previous example, $I_a = 1$ amp., $E = 220$ volts, $n = 60$ cycles per second, if the voltmeter takes a current 0.06 amp. lagging 1° behind its potential difference?

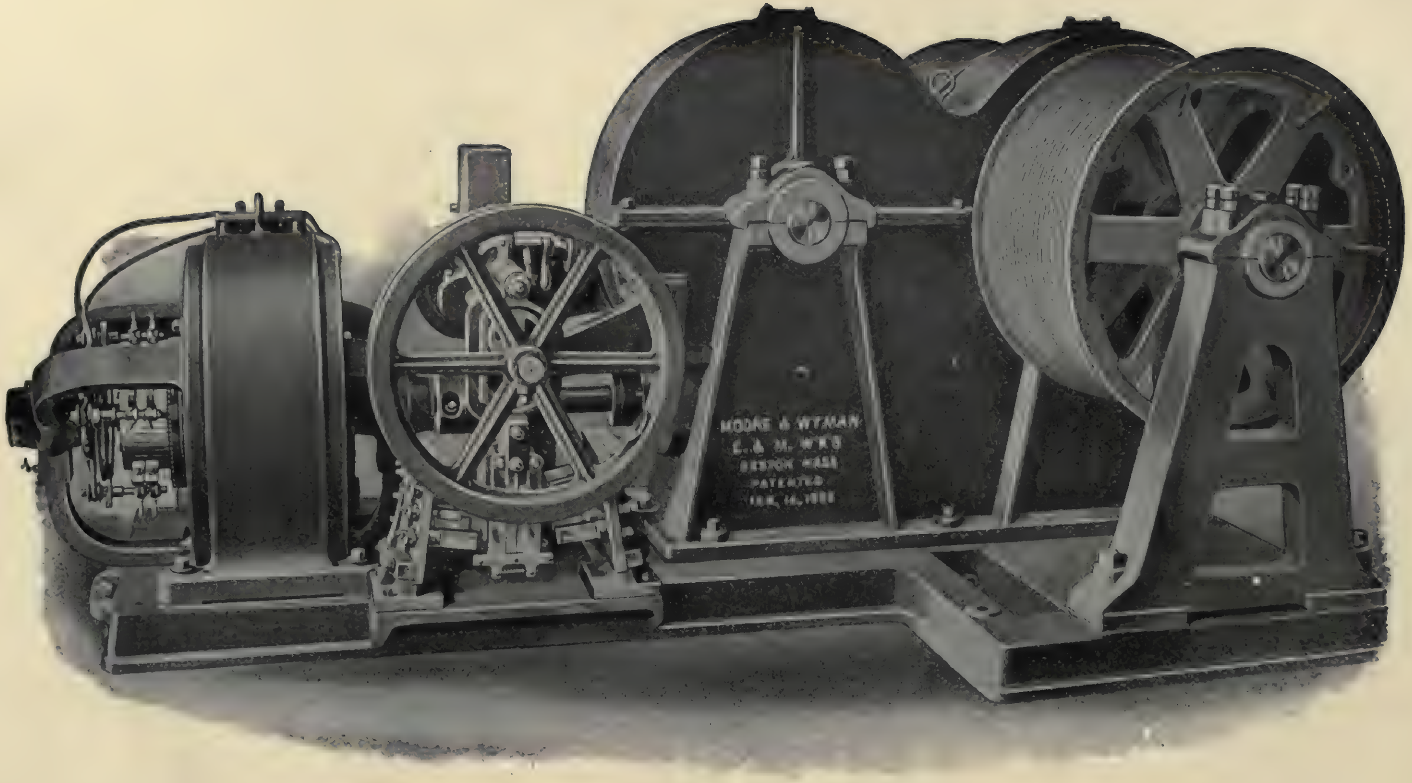
Solution.

$$\sin 1° = 0.01745, \cos 1° = 0.99985$$

$$I_c = 0.00105 + \sqrt{0.9964012} = 0.00105 + 0.99820$$
$$= 0.99925 \text{ amp.}$$

As the correction of the current is far below the accuracy with which the ammeter may be read, no correction in the computed capacity of the condenser should be made.

Example. If the current observed was 0.1 amp., the other data



STANDARD ELEVATOR MOTOR. DIRECT-CONNECTED.

Holtzer-Cabot Electric Company.

remaining the same as in the previous example, what correction, if any, should be made?

Solution.

$$I_c = 0.00105 + \sqrt{0.0064012}$$
$$= 0.00105 + 0.08001 = 0.08106 \text{ amp.}$$

The uncorrected formula gives $C = 1.206$ microfarads
The corrected formula gives $C = \underline{0.978}$ "
The difference is 0.228 "
which is 19%, a difference much too large to be ignored.

MEASUREMENT OF SELF-INDUCTANCE

Most methods of measuring inductance are too difficult for the readers of this book. The difficulty is due to the fact that a coil of wire which has inductance, has resistance also. During the increase of a current the inductance acts as a false resistance which makes the resistance appear too high. During the current's decrease, however, the inductance acts as a negative resistance, which makes the resistance appear too low. In the case of an alternating current the effect is to make the apparent resistance, called the *impedance*, higher than the real resistance. Algebraically expressed we have

$$\text{Impedance} = \sqrt{R^2 + 4\,\pi^2\,n^2\,L^2} = \frac{E}{I},$$

in which R is the real resistance in ohms, $\pi = 3.1416$, n the frequency in cycles per second, L the inductance in henrys, E the e. m. f. in volts, and I the current in amperes. The impedance of a coil is therefore not a constant quantity if R and L are constant, but depends on the frequency n. For commercial lighting n is usually 60, and for power circuits 25 cycles per second. Coils which have an iron core do not have a constant self-inductance, for the latter, with increase of current, rises slightly to a maximum and then falls off greatly for large values of the current.

Alternating-Current Method. If in a circuit, Fig. 51, the current through a coil of known resistance R and unknown inductance L, is measured by means of an ammeter A (two views of a well-known commercial instrument are shown in Figs. 52 and 53), and the potential difference E over the coil is measured by a voltmeter V, we have the following relation

$$2 \pi n L = \sqrt{\frac{E^2}{I^2} - R^2},$$

or

$$L = \frac{1}{2 \pi n} \sqrt{\frac{E^2}{I^2} - R^2}$$

Example. In a circuit for which the frequency $n = 60$ cycles per second, $R = 0.1$ ohm, $E = 110$ volts, and $I = 10$ amperes, what is the value of the inductance L?

Ans. $L = 0.0292$ henry.

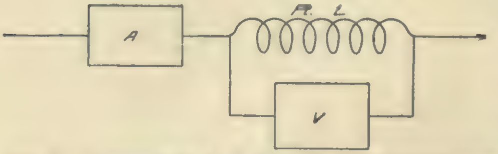


Fig. 51. Diagram for A. C. Method of Self-Inductance Measurement.

If the resistance or inductance is very high, so that the total current is small, a correction must be made for the portion of the current passing through the voltmeter. The corrected formula is very complicated when expressed directly in terms of L, l, R, r, the inductances and resistances of the coil and the voltmeter respectively, n the frequency, E the potential difference, and I_a the current through the ammeter. If the tangents of the lag of the current in the two branches of the circuit are for the coil

$$\tan b = \frac{2 \pi n L}{R},$$

and for the voltmeter circuit

$$\tan a = \frac{2 \pi n l}{r},$$

we get the equation for the cosine of the difference between a and b

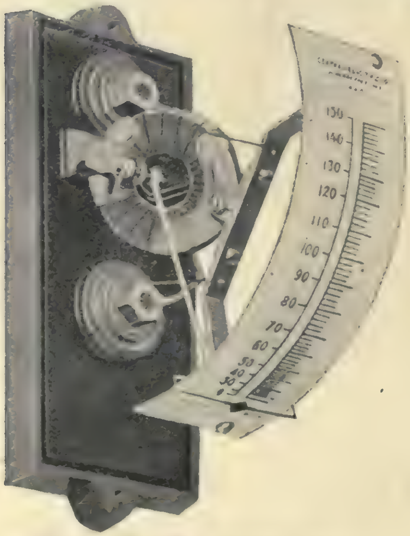


Fig. 52. Thomson Inclined Coil A. C. Ammeter.

$$\cos\ (\pm (a - b)) = \frac{rR}{2}\left(\frac{I_a^2}{E^2} - \frac{1}{r^2} - \frac{1}{R^2}\right)$$

Usually b is greater than a, so we write the formula

$$\cos\ (b - a) = \frac{rR}{2}\left(\frac{I_a^2}{E^2} - \frac{1}{r^2} - \frac{1}{R^2}\right)$$

As the constants of the voltmeter are supposed to be known, the angle a is known; therefore b may be determined and we finally get

$$L = \frac{R\ tan\ b}{2\ \pi\ n}$$

If b is so small that the difference between a and b is not greater than a, there is always the possibility that the previous formula is the cosine of $(a - b)$. To determine which result to take, it is necessary to repeat the experiment with additional resistance in one of the two branches, and to take the value of L that equals one of the previous solutions. As a rule, however, the difference between a and b will be greater than a, and the incorrect result will lead to a negative value for b. As b must be positive, the negative result is rejected as impossible.

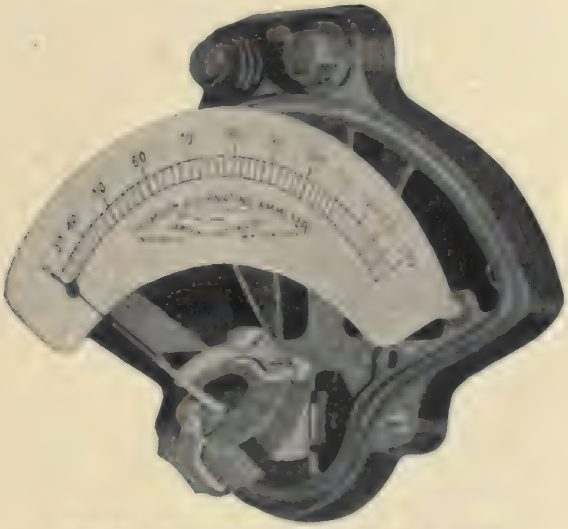


Fig. 53. Thomson Inclined Coil A. C. Ammeter.

Bridge Method. Two self-inductances may be compared by a modification of the Wheatstone's bridge method. In the simplest of many bridge methods the coil of unknown inductance X is one arm of the bridge; a double coil, Fig. 54, whose inductance L may be varied by rotating one part to various positions inside the other part, and whose inductance is known for each position and marked by a pointer on a circular scale for each position, is inserted in an adjacent arm. The other arms are non-inductive resistances R_1 and R_2. The arrangement is shown in Fig. 55. The inductive branches have certain resistances R_3 and R_4. A regular Wheatstone's bridge balance is obtained by adjusting the resistances R_1 and R_2, care being taken to close the key K_2 in the galvanometer branch several seconds after closing the key K_1 in the battery branch. This precaution is necessary to insure that the currents are steady when the galvanometer key is closed, as inductive effects are produced only when the current is changing in value. When a balance is obtained $R_1 : R_2 :: R_3 : R_4$. If now the galvanometer key K_2 is closed first, the false resistance due to inductance, will cause the galvanometer to deflect when the battery circuit is closed. After oscillating a number of times the galvanometer finally comes to rest at its zero position. On opening the battery circuit the first deflection is in the opposite direction. If, now, the variable inductance is adjusted until there is no deflection on closing the battery circuit, the galvanometer circuit having been closed in advance, the false resistances due to inductance must increase the apparent resistances in both inductive branches in proportion to their real resistances, from which it follows that

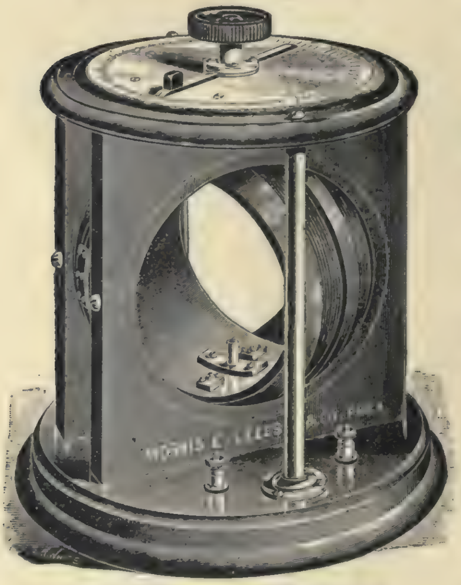


Fig. 54. Variable Self-Inductance.

$$X : L :: R_3 : R_4 :: R_1 : R_2,$$

and we get the relation

$$X = L\frac{R_1}{R_2}$$

If no variable standard of inductance is available, there are various modifications of the bridge method which may be used. These methods are as a rule very complicated and consequently beyond the scope of this course.

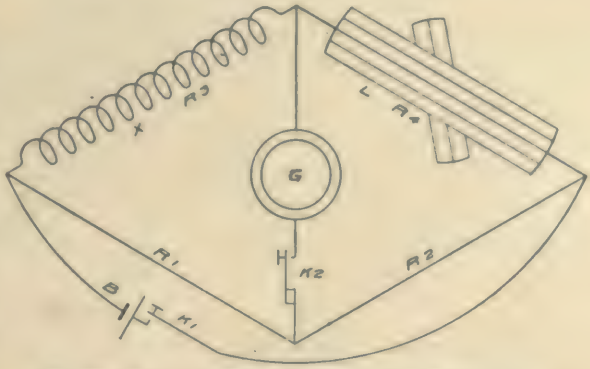


Fig. 55. Diagram of Bridge Method of Self-Inductance Measurement.

Condenser Method. The self-inductance of a coil may be compared with the capacity of a condenser. The bridge is set up as indicated in Fig. 56. The condenser of capacity C is in parallel with M which is one part of a constant resistance R_1. $R_1 = M + N$. R_2 and R_3 are resistances, one or both of which may be varied at will. The coil of resistance R_4, whose inductance L is to be measured, is in the fourth arm of the bridge. The galvanometer G, battery B, and keys K_1 and K_2 are as usual. The resistances are adjusted in R_2 and R_3 until a balance is reached, when K_2 is closed several seconds after closing K_1.

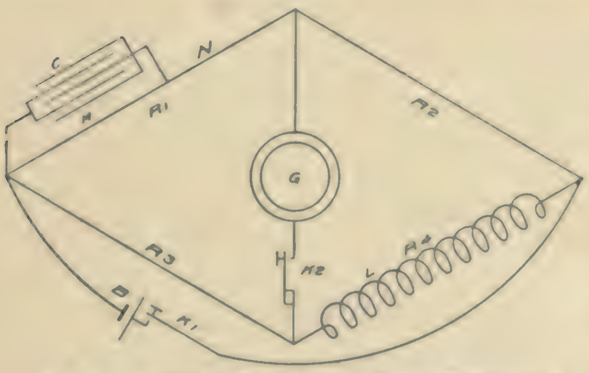


Fig. 56. Diagram of Bridge Method of Self-Inductance Measurement.

Then $R_1 : R_2 : : R_3 : R_4$, the usual Wheatstone's bridge relation. The galvanometer key K_2 is next kept closed and resistance shifted between M and N, care being taken to keep $M + N = R_1$ constant, until no deflection is produced at the instant of closing K_1. The explanation of the method is quite complicated, but leads to the simple result,

$$L = \frac{C\ R_2\ R_3\ M^2}{R_1^2\ 10^6} \text{ henries.}$$

C is in microfarads, R_1, R_2, R_3, and M in ohms, and the result for L in henries.

Example. The resistance R_1 was kept constant at 1,000 ohms, part of which M, when a balance was reached, was 516 ohms. $R_2 = 1{,}000$ ohms, $R_3 = 1{,}260$ ohms, and $C = 1$ m. f., makes up the balance of the data. What was L?

Ans. $L = 0.3355$ henry.

MEASUREMENT OF MUTUAL INDUCTANCE

If two electric circuits are in the neighborhood of one another, the increase or decrease of the current of one will produce a change in the magnetic field which will act to produce an e. m. f., and consequently a current in the second circuit if it is closed. If the current in one circuit varies at the rate of one ampere increase or decrease per second and an e. m. f. of one volt is produced in the second circuit, we say the mutual inductance is one henry. If the mutual inductance is constant, the e. m. f. produced in the second circuit is proportional to the rate of change of current in the first; also larger inductances produce proportionately larger e. m. f.'s in the second circuit with equal rates of change of current in the first. Algebraically expressed, if I_1 and I_2 represent any two values of the current, supposed to be increasing at a uniform rate, and t is the interval of time between these values of the current, and if E is the e. m. f. produced in the second coil whose mutual inductance with respect to the first is M, then

$$M\frac{I_2 - I_1}{t} = E$$

The inductance between the coils is called *mutual* because a certain increase of current in either will produce the same e. m. f. in the other regardless of which circuit has the original current. The relation is therefore *mutual.* If the circuit has an iron core the mutual inductance is not strictly constant, but with increasing current increases to a maximum and then falls again. As it is very difficult, if not impossible, to control the precise rate of change of the current so that it will increase at a uniform rate, either of two methods may be used to obtain the value of M without keeping the rate of change of I constant.

Ballistic Galvanometer Method. In this method the second circuit, called the *secondary* circuit, is of known resistance R_2, and includes a ballistic galvanometer G and sufficient extra non-inductive resistance T_2 to control the deflection within reasonable bounds. The other circuit, called the *primary* circuit, includes a key K, an adjustable resistance r_1, a battery B, and an ammeter A. The arrangement is shown in Fig. 57. The primary coil is P and the secondary S.

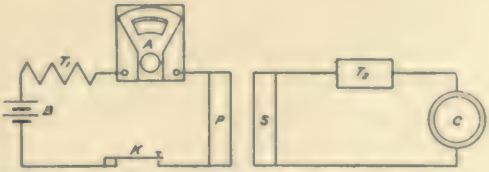


Fig. 57. Diagram of Ballistic Method of Mutual Inductance Measurement.

On closing the key K the current in P begins to increase and the galvanometer G begins to deflect. If we make no allowance for the false resistance due to the self-inductance of the secondary circuit, the current I_2 in the secondary is $I_2 = \frac{E}{R_2}$. As the current I_1 in the primary requires a considerable part of a second nearly to reach its maximum or steady value, it is evident that the secondary current I_2 will require at least an equal time to rise from zero to its maximum and to fall nearly to zero again. Theoretically it takes an infinite time for this to happen, but if the total resistance R_1 in the primary and R_2 in the secondary are reasonably large in comparison with their self-inductance, the time practically necessary is a second or so. The current I_2 in the secondary will, therefore, during the times that it flows, cause a certain quantity Q of electricity to pass through the galvanometer. If the ballistic galvanometer has a long period of swing—a condition required of ballistic galvanometers—practically the whole of the quantity Q will pass before the galvanometer gets far from its zero position. As the e. m. f. of the secondary is proportional to the rate of increase of the primary current I_1, it is evident that the *total* quantity flowing in the secondary will depend on the *total* rise of current in the primary in precisely the same way as the current *at any instant* in the secondary depends on the *rate of increase* of the current in the primary. As before mentioned, we have ignored the false resistance due to the self-inductance of the secondary. We have learned, however, in the chapter on self-inductance, that during the rise of a current the self-inductance increases the apparent resistance, but during its fall the opposite effect is produced. Therefore, during the rise and fall of the current in the secondary, no appreciable error is caused by ignoring the self-inductance of the secondary. The final result is $M I_1 = Q R_2$, or

$$M = \frac{Q R_2}{I_1}$$

To get the value of Q we must know the relation between the throw d_2 of the ballistic galvanometer to the quantity of electricity producing the throw. This may be found by charging a standard condenser of known capacity C by a standard cell of known e. m. f. E_s, and noting the deflection d on discharging the condenser through the ballistic galvanometer. As the charge of the condenser is $E_s C$, we obtain the result

$$Q : d_2 :: E_s C : d,$$

or

$$Q = \frac{d_2 E_s C}{d}$$

Substituting in the earlier equation the value of Q and expressing the capacity of the condenser in microfarads,

$$M = \frac{d_2 E_s C R_2}{d I_1 \times 10^6}$$

Example. The current I_1 in the primary coil rises on closing the circuit to 1 ampere. The total resistance in the secondary circuit is 10,000 ohms. The deflection produced is 21.3 cm. With a Weston normal cell of 1.0184 volts and a condenser of 0.2 microfarads, a deflection of 23.0 cm. was produced on discharging the condenser through the galvanometer. What is the mutual inductance M?

Ans. $M = 0.001886$ henry.

Alternating-Current Method. The previous method may be varied by putting in the secondary an alternating-current voltmeter of high resistance, and in the primary an A. C. ammeter, an e. m. f. source of sine form, and whatever resistance is needed to control the current. From the theory of alternating currents, the e. m. f. produced in the secondary is

$$E_2 = 2 \pi n M I_1,$$

or

$$M = \frac{E_2}{2 \pi n I_1},$$

when n is the frequency in cycles per second, M the mutual inductance, and I_1 the primary current. This relation assumes that the current in the secondary is too small to affect the flux of magnetic lines crossing over from primary to secondary. If the resistance of the secondary coil is small in comparison with that of the voltmeter, the voltmeter reading E_v is taken as E_2. If the coil is of too high resistance to make the last assumption allowable, the reading must be multiplied by $\frac{R_2}{R_v}$, when R_2 is the total resistance of the secondary and R_v the resistance of the voltmeter. We then get

$$E_2 = \frac{R_2}{R_v} E_v = 2 \pi n M I_1,$$

or

$$M = \frac{R_2 E_v}{2 \pi n R_v I_1}$$

If the secondary current I_2 is too large for its magnetic effect to be ignored, or if the current in the primary does not follow a simple sine law, the problem becomes too complex for easy solution.

Example. The current I_1 in the primary is 1.1 amperes, the frequency n is 60 cycles per second, the resistance of the secondary coil is negligible. The reading of the voltmeter E_v is 110 volts. What is the mutual inductance M? Ans. $M = 0.2653$.

Carey-Foster Method. Let a battery of constant e.m.f. be connected in series with one of the two coils P whose mutual inductance is to be determined, a known resistance R_1, and a key K, Fig. 58. Let the ballistic galvanometer G and another resistance R_2 be connected in series with the other coil S. Then if I be the steady current produced by the battery B through P, and M be the mutual inductance, and r be the resistance of the circuit through S R_2, and the galvanometer, then the quantity of electricity Q, passing through the galvanometer on closing or opening the circuit will be

$$Q_1 = \frac{MI}{r}$$

Next, if the galvanometer be removed from this circuit and put in series with a condenser whose capacity is C, which is connected as a *shunt* to the resistance R_1, on opening or closing the battery circuit the quantity of electricity

$$Q_2 = IR_2C$$

By combining these two equations it is possible to find the relative values of C and M. In practice it is much more desirable to combine

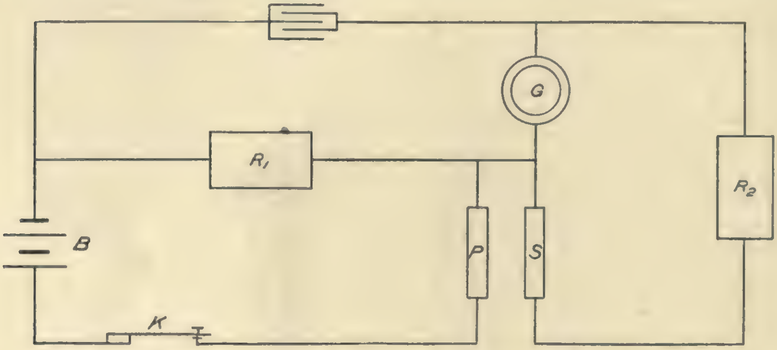


Fig. 58. Diagram of Carey-Foster Method of Measuring Mutual Inductance.

these two circuits, as shown above, so that the charge and discharge of the condenser and the currents produced at the same time in S by mutual induction are in the same direction through C, R_2, and S. Then if the resistance R_1 and R_2 and the capacity C are adjusted until no deflection of the galvanometer is produced, the following may be written:

$$Q_1r = MI, \text{ but } Q_1 = IR_1C; \text{ hence } M = CR_1r$$

Attention is called to the fact that in order that the galvanometer current may be 0 at every instant during the establishment of the steady current, it is essential that the coefficient of self induction of the coil S should be equal to the coefficient of mutual induction. Under this condition it is possible to replace the galvanometer by a telephone.

Example. Small Induction Coil, no iron core. Resistance of secondary, 194 ohms. Capacity of condenser, 4.9.26 microfarads

The secondary coil could slide endways remaining coaxial with the primary. The following are the results with the centers of the two coils as nearly coincident as possible:

R_1	r	R_1r (C. G. S. Units)	R_1	r	R_1r (C. G. S. Units)
15	194 + 217	6165×10^{18}	10	194 + 423	6170×10^{18}
14	+ 247	6174	9	+ 490	6156
13	+ 282	6188	8	+ 576	6160
12	+ 322	6192	7	+ 688	6174
11	+ 367	6171	6	+ 835	6174

$$\text{Mean value of } \frac{M}{C} = 6172.4 \times 10^{18}$$

Hence

$$M = 4.926 \times 10^{-15} \times 6172 \times 10^{18} = 3.04 \times 10^{7} \text{ or } .0304 \text{ henrys.}$$

MAGNETIC MEASUREMENTS

Certain materials, notably iron (or steel), nickel, and cobalt, have a property known as *magnetism*. These materials when magnetized have the property of attracting soft iron. The modern view of magnetism is that it is a property of the individual molecules of a body. A body which seems to be unmagnetized probably has its molecules arranged in more or less irregularly formed closed chains, Fig. 59, which produce no outside effect. To magnetize a body, it is, according to this theory, necessary to break the chains and to rearrange the connections of the molecules so that the ends of the chains of molecules come out at points on the surface where so-called magnetic charges appear, Fig. 60. The centers of action of these chain ends are called *poles*. In the simplest magnets there are two poles, and if the magnet is free to turn in a horizontal plane, one of the poles is turned toward the north and the other toward the south approximately. In general, the magnetic meridian, determined by the line joining the poles when at equilibrium in the horizontal plane, does not agree exactly with the geographical meridian. The line of no

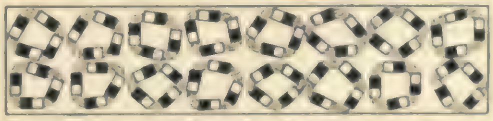


Fig. 59. Supposed Molecular Condition of a Piece of Unmagnetized Steel.

variation at present is located near the eastern shore of Lake Michigan and is moving westward. A century ago it was near the eastern end of Lake Erie. For points to the east of the line of no variation, the magnetic compass points west of north; and for points west of this line of no variation, it points east of north. The north seeking pole of a magnet is commonly called the *north pole* and the other the *south pole* of the magnet. If the magnet is free to turn in all directions, the north pole will dip downward and the south pole rise upward for points in the northern hemisphere and *vice versâ* for points in the southern hemisphere. The dip in Chicago is in the neighborhood of 70°.

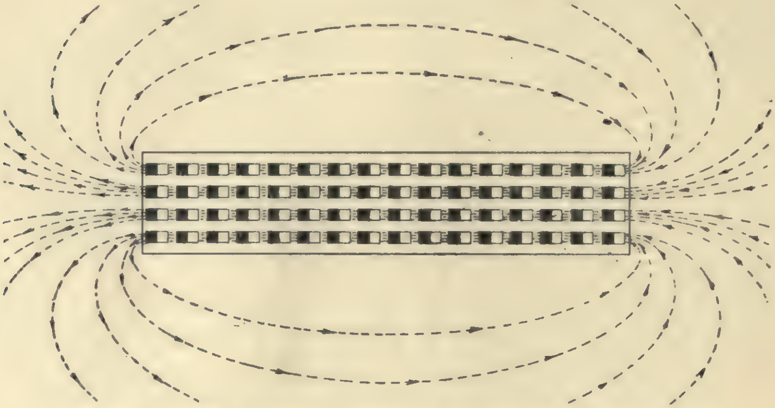


Fig. 60. Supposed Molecular Condition of a Magnetized Piece of Steel.

From the above it appears that the earth has a magnetic field, meaning by magnetic field an extent of space where magnetic forces are to be found. If a magnet with poles 1 cm. apart and of unit strength is in a unit magnetic field, it will act on each pole with a force of one dyne; and if the poles are turned so that the directions of the forces are at right angles to the line connecting the poles, a unit turning moment, or torque, is exerted on the magnet. In the first chapter of this book, unit magnetic pole was defined as a pole which, at a distance of one centimeter in air from a like pole, produces a repulsion of one dyne of force. It appears then that a magnetic field has both direction and magnitude, and is what is called a *vector* quantity. To define a vector quantity both magnitude and direction must be known.

Methods of Magnetizing. Besides natural magnets, composed of the magnetic oxide of iron and known as *loadstones*, artificial magnets may be made by subjecting hard steel to a magnetic field. The magnetic field used may be due to a loadstone, or an artificial magnet previously made, or a magnetic field due to an electric current in a coil of wire. Before 1819, when Oersted discovered the magnetic field produced by a current, the source of all artificial magnets was directly or indirectly the loadstone. Permanent magnets nowadays are practically all magnetized by means of electric currents.

Lines of Force and Permeability. To Michael Faraday we owe the notion of lines of force to express the vector quantity defining the magnetization. The direction of the lines is used to indicate the direction of magnetization, and the number of lines per square centimeter indicates the magnitude of the magnetization. The numbers of lines per square centimeter is commonly called the *flux density* or *flux of force* per square centimeter. The unit value occurs when there is one line per square centimeter, and is called the *gauss*. The symbol B is used to express this quantity algebraically. As different materials when put in equal fields take different degrees of magnetization, the relation of field strength to flux, known as the *permeability*, must be known. If H indicates the field strength, B the flux per sq. cm., and μ the permeability, we have the relation

$$B = \mu H$$

When the section considered has an area A sq. cms. and the average flux intensity is B, the total flux designated by Φ is algebraically expressed as

$$\Phi = B A = \mu H A$$

The unit in which Φ is measured is the Maxwell and is equal to one line of force.

If the lines of force pass from one material into another of different permeability μ, the lines representing B and Φ will usually suddenly change direction at the surface of separation between the materials, commonly called *media*, except in the case that the lines are normal to the surface. If the permeabilities of two media are μ_1 and

μ_2, and the angles between the normal and the lines in the two media are a_1 and a_2, we have the relation

$$\frac{\tan a_1}{\tan a_2} = \frac{\mu_1}{\mu_2}$$

Lines of force follow by preference paths of high permeability, though, other things being equal, they tend to follow the shorter paths. Consequently it rarely happens that the lines are straight, as they converge toward spaces filled with bodies of high permeability and there diverge again in spaces of low permeability. In general the total flux Φ distributes itself so that, length of path and permeability considered, it takes the easiest course. A line of force never ends, but always returns on itself. Many writers carelessly confuse and use the same unit (the gauss) for measuring B and H, for both are vector quantities and may be represented by lines. To avoid confusion we shall not represent H by lines. For highly magnetic materials, B is much greater than H. In the case of iron the ratio may be as high as $\mu = 3{,}000$ for moderate values of B. The value of μ is not constant for the same material for different values of B. In the case of soft iron the permeability for low values of B may be about $\mu = 120$, rising to $\mu = 2{,}000$, or in good samples $\mu = 3{,}000$, when B reaches a value between $B = 5{,}000$ to $B = 8{,}500$. For nickel and cobalt the highest value of the permeability is about $\mu = 200$. As a standard of comparison the permeability of air is taken as $\mu = 1$ and is believed to remain sensibly constant for all values of B. It follows that in air $H = B$ (numerically). Materials more magnetic than air, for which $\mu > 1$, are called *paramagnetic.* Materials less magnetic than air, for which $\mu < 1$, are called *diamagnetic.* No magnetic material is without permeability, that is $\mu = 0$; in fact, even the most diamagnetic material, bismuth, is within a fraction of one per cent as permeable as air. Magnetic insulation is therefore impossible and to avoid magnetic leakage of lines of force from a prearranged path, it is necessary to distribute the *magnetomotive force* over the whole path.

Magnetomotive Force. By analogy with electric circuits, where the potential difference over each unit length of the circuit is found by multiplying the current by the resistance of that unit length, or dividing the current by the conductivity (the reciprocal of resistance) for the unit length, we see that in a part of a magnetic circuit, one centimeter long and one square centimeter in section, μ is analogous to the conductivity per cm. cube of an electric circuit. B is analogous to the current per sq. cm. of section of the conductor and H is analogous to the potential difference per centimeter length. H is called the magnetomotive force per unit length, and the total magnetomotive force is the average value of H multiplied by the length of the circuit l. It follows that the magnetomotive force (m. m. f.) is

$$\text{m. m. f.} = \mathsf{H}\, l$$

If the magnetic field is produced by a current in a wire, the intensity of the field is greatest at the surface of the wire and falls in value to zero at the middle of the wire, and outside the wire falls in value according to the law of the reciprocal of the distance from the center. If, however, the wire is coiled into a long, straight coil of uniform section, called a *solenoid*, the magnetic field for the portion far from the ends is practically zero outside the solenoid and of uniform value inside the solenoid. If there are n turns of wire per centimeter and a current of I amperes, the inside magnetic field is

$$\mathsf{H} = 0.4\,\pi\, n\, I = 1.2566\, n\, I$$

If the whole number of turns of wire is N, the magnetomotive force is

$$\text{m. m. f.} = 1.2566\, N\, I$$

The unit of m. m. f. is the *gilbert*, or that value of magnetic force which will establish one line or one maxwell per centimeter cube of air. Many practical authorities prefer to express the m. m. f. in *ampere turns* $N\,I$ omitting the factor 1.2566. This leads to some confusion if the fact is not made clear by stating that the m. m. f. is in ampere turns. If a long solenoid is bent into the form of a ring, it is called a *ring* solenoid. If the width of the ring is small in comparison with its diameter, it is assumed that the average value of H is equal to its value along the central line of the ring.

Reluctance. If a circuit is l centimeters long and averages A sq. cm. in section, the reluctance R of the whole circuit is

$$\mathsf{R} = \frac{l}{A\,\mu}$$

The unit in which reluctance is measured is the *oersted*.

By analogy with Ohm's law the magnetic flux Φ is

$$\Phi = \frac{\text{m. m. f.}}{\text{reluctance}} = \frac{\text{m. m. f. } A\,\mu}{l} = \text{B}\,A = \mu\,\text{H}\,A$$

Hysteresis. When iron or steel has been magnetized and the magnetizing force removed, a portion of the magnetization will still remain as more or less *permanent* magnetization. If next the magnetizing force is applied in the reverse direction, the magnetization will not be reversed until the m. m. f. has reached a certain value, *i. e.*, until H reaches a certain value. The residual value of B when the field is reduced to zero is called the *remanence* or *retentiveness* by some writers. The reverse field, m. m. f., necessary to reduce B to zero is called by the barbarous term (as Professor Mascart puts it) of *coercive force.* Further increase of the reverse m. m. f. will cause a rapid rise of B. With repeated cycles of change between positive and negative m. m. f.'s the values of H and B go through cycles. The tendency of B to lag behind H is called *magnetic lag* or *magnetic hysteresis,* hysteresis being the Greek word for lagging behind. A certain amount of energy is expended in the cycle and appears in the form of heat generated in the iron. This loss of energy per cycle is repeated n times per second, and the power used is known as the *hysteresis loss,* and is measured in watts per cubic centimeter. Sometimes the energy lost per cycle is measured in joules. One joule equals 10,000,000 ergs. The relation of H and B during the hysteresis cycle may be expressed in the form of a curve plotted in terms of H (horizontally) and B (vertically). The curve shown in Fig.

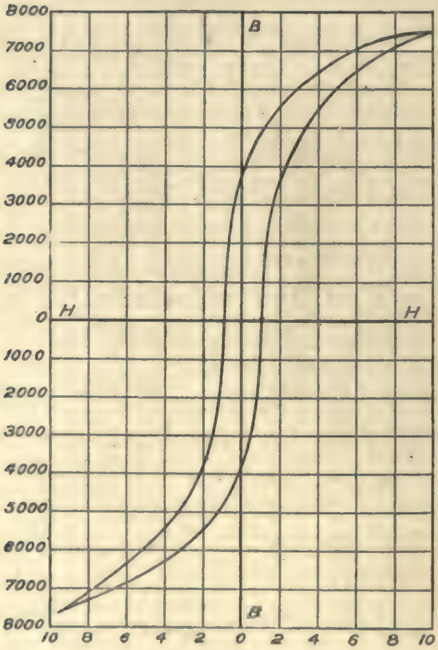
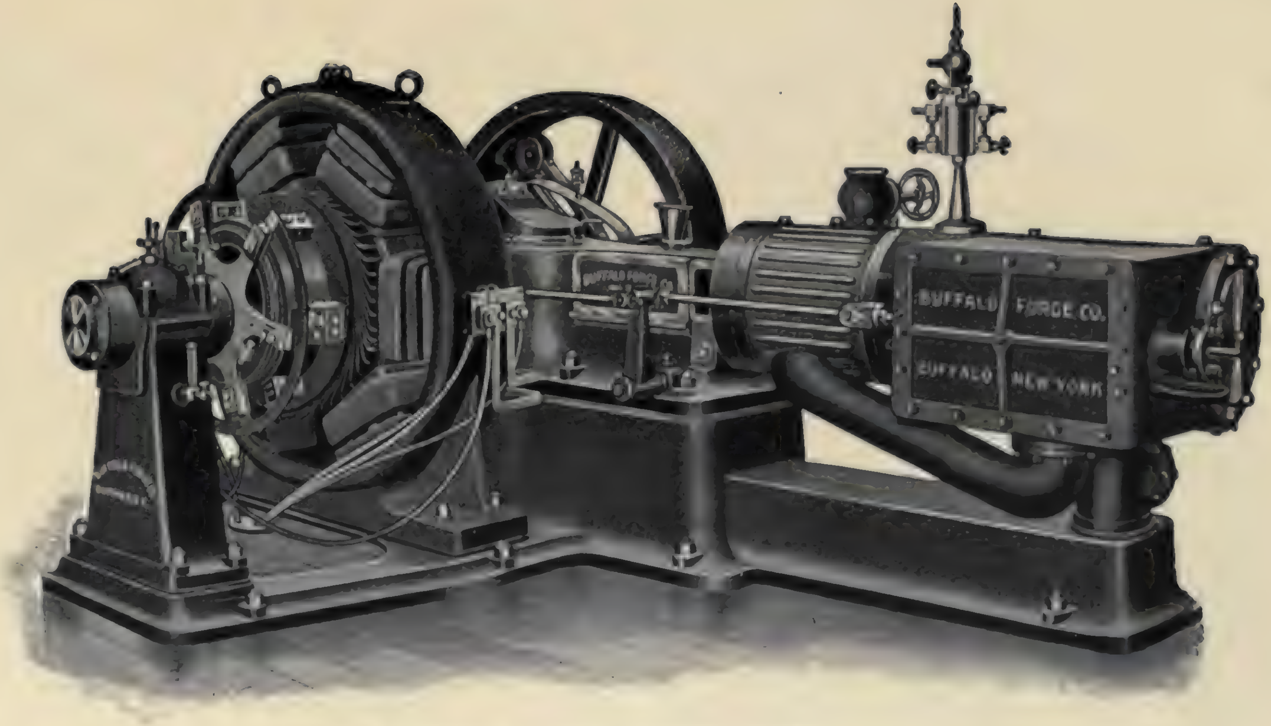


Fig. 61. Hysteresis Diagram.



HORIZONTAL TANDEM-COMPOUND ENGINE.
Direct-Connected to Generator.
Buffalo Forge Company.

61 is known as a *hysteresis curve.* If H and B are plotted to scale, the area of the curve divided by 40,000,000 π, or 125,660,000, gives the energy lost per cycle in joules. For measurements of hysteretic losses the sample may be made into the form of a ring with small difference between its largest and smallest radius. The ring may then be wound with a coil of wire in the form of a ring solenoid and the current and turns in the coil will determine the m. m. f. and consequently **H** in the core.

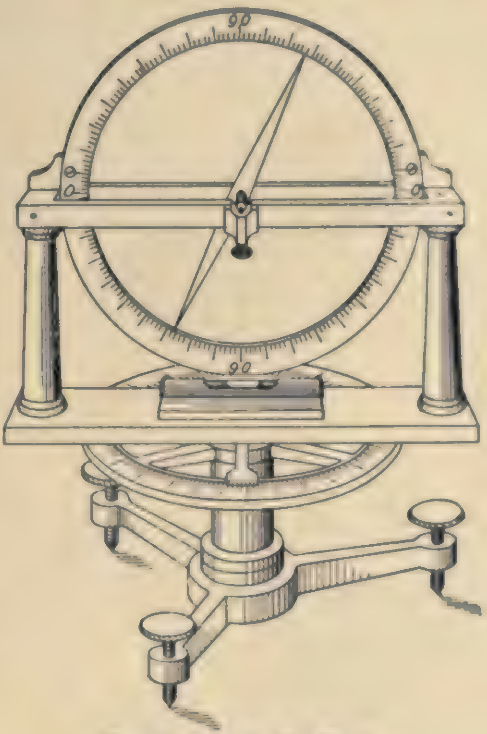


Fig. 62. Magnetic Dip Needle.

Magnetic Dip. *By Dip Needle.* If a long and slender magnetic needle, Fig. 62, with pointed ends is mounted on an axis passing precisely through its center of gravity, at the middle of an accurately graduated circle standing vertically in the magnetic meridian, the north pole of the needle will point downward from the horizontal by an angle equal to the magnetic dip. The angle of dip may then be read directly from the circle. As, however, it is difficult to magnetize the needle with exact uniformity, the bearing should be made reversible so that the needle may be turned over. Any irregularity of magnetization may be eliminated by taking the mean of the two readings of the magnet in the two positions. In case the bearing fails to pass exactly through the center of gravity, the error may be compensated by reversing the magnetization of the needle, care being taken to use the same magnetic field as before, and then repeat the observations of the dip with the magnet in both positions. The mean of the four readings will give the value of the dip. If the divided circle is not in the magnetic meridian, an error will be caused which is slight for slight deviations from the meridian. A compass needle mounted over the divided circle will locate the magnetic meridian well enough for practical purposes.

Earth Inductor Method. Another method is by use of the earth inductor which is a coil of wire mounted in a frame and which may be turned about an axis in the plane of the coil. No iron or other magnetic material should be used in the apparatus. The frame is carried on a support by which the axis of rotation may be made vertical or horizontal. The apparatus is shown in Fig. 63. All heavy parts are made of brass which is practically non-magnetic.

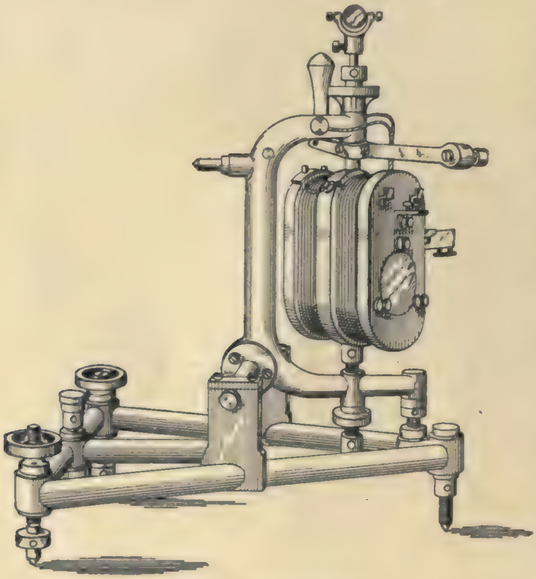


Fig. 63. Earth Inductor.

If the coil is turned about a vertical axis, as shown in the figure, from an east and west plane through 180° to the reverse position in the same plane, the number of lines = B A cos δ of the earth's magnetic field passing through the coil, will be cut by the coil, and if a ballistic galvanometer is in the circuit, its deflection d_1 will be proportional to the flux cut. If now the axis of rotation be made horizontal and the coil horizontal, a reversal in position will cut the number of lines = B A sin δ of the earth's magnetic field passing through the coil. The resulting deflection d_2 of the ballistic galvanometer is proportional to the flux cut. We then have the relation

$$\tan \delta = \frac{d_2}{d_1}$$

If the deflections are small they may be increased by reversing the position of the coil on the return swing of the galvanometer, and continuing until the amplitude of swing becomes constant. The deflections in two positions of the axis of the coil are proportional to the *horizontal* and the *vertical* components respectively of the magnetic field, and the ratio of the second to the first gives the tangent of the dip of the earth's field.

The angle of dip varies from + 90° at the earth's north magnetic pole to – 90° at the south magnetic pole. It is zero at the magnetic equator.

The Earth's Magnetic Field. If in the previous method, the data of the earth inductor and of the ballistic galvanometer are known, the value of B may be determined. As the experiment is performed with air as the medium, the value of μ is 1, and H is numerically equal to B. The horizontal component of the earth's magnetic field is frequently spoken of as H, meaning thereby the *horizontal* component. In the same way V is the vertical component. The tangent of the angle of dip is the ratio

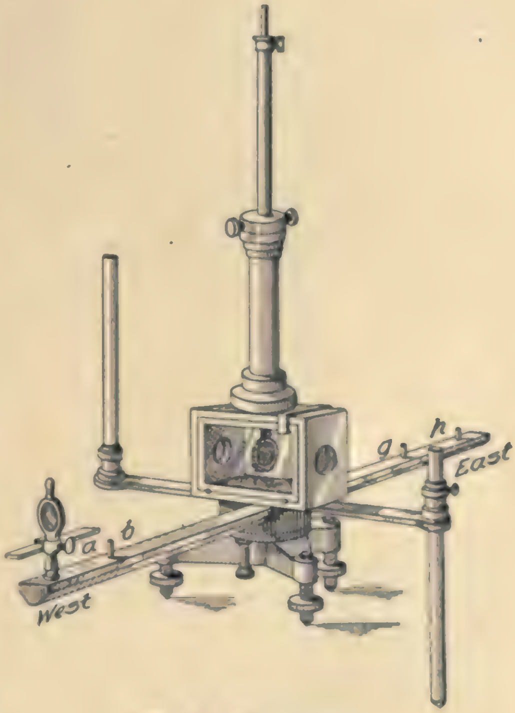


Fig. 64. Magnetometer.

$$\frac{V}{H}$$

Magnetometer Method. The horizontal component may be measured by means of two magnets, one of which is of light weight and the other relatively large and heavy, both carrying mirrors. The little magnet and mirror may be suspended at the center of an instrument called a *magnetometer,* Fig. 64. The second magnet, of considerable size, is mounted on a support at its center at a fixed distance to the east of the little magnet and in an east and west position (point *g* of the figure). The small magnet takes up a position parallel to the resultant of the horizontal component of the earth's field and that of the large magnet. By means of a telescope and scale at a known distance, the angle of the deflection is measured. The other pole of the large magnet is now turned toward the small magnet by turning the large magnet end for end. The deflection measured by the telescope and scale should be as before, only in the opposite direction. The large magnet is now transferred to a support *b* at an equal distance to the west of the small magnet, and the observations repeated, obtaining two more deflections. All four deflections should be equal. If they differ slightly the mean is taken; if they differ much, something is wrong with the arrangement and the apparatus should be examined and the trouble corrected. The observations are now repeated at a larger distance (points *a* and *h*), and four more observations taken. From the data, assuming that the magnetic field falls off according to the inverse square of the distance from the poles of the magnet, a pair of equations may be formed from which the strength of the magnet's poles in terms of the horizontal component of the earth's field and their distance apart may be calculated. This distance apart of the poles will be found to be somewhat less than the length of the large magnet. The product of the pole strength and length between poles is called the *magnetic moment* of the magnet, represented by M. If $r_2 =$ the larger distance, r_1 the smaller distance, and Φ_1 and Φ_2 the deflections, we get

$$\mathsf{M} = \frac{\mathsf{H}}{2} \, \frac{r_2^5 \tan \Phi_2 - r_1^5 \tan \Phi_1}{r_2^2 - r_1^2}$$

The large magnet is now hung up by a fine wire and set to vibrating. The period of vibration T_1 is determined by measuring with a stop watch the time of a considerable number of vibrations and finding the time of a single swing. If K_1 is the moment of inertia and θ the correction for the rigidity of the wire, we have

$$T_1 = \pi \sqrt{\frac{K_1}{\mathsf{M}\,\mathsf{H}\,(1 + \theta)}}$$

As there may be some difficulty in computing the moment of inertia

K_1, it is usual to add a brass ring of rectangular section and easily computed moment of inertia K_2. This ring must be placed on top of the magnet so that its center lies on the prolongation of the suspending wire. The moments of inertia are then added to get the total moment. There are reference marks on opposite ends of a diameter of the ring and corresponding marks on portions of a circle of the same radius of the ring marked on the top surface of the magnet to ensure precise centering. With the ring in position, the new time T_2 of vibration is determined.

$$T_2 = \pi \sqrt{\frac{K_1 + K_2}{MH(1 + \theta)}}$$

θ is determined by turning the torsion head, from which the magnet is hung by the wire, through a considerable angle and determining by the telescope and scale the angle through which the magnet follows. This enables one to compute how much effect the rigidity of the wire has on the restoring force which is due principally to the earth's field. If on turning the torsion head an angle α, the magnet follows an angle β, there is obtained, $\theta = \frac{\beta}{\alpha - \beta}$. Combining the earlier equations gives

$$MH = \frac{\pi^2 K_2}{(1 + \theta)(T_2^2 - T_1^2)}$$

Substituting the value of M previously obtained we get on solving for H

$$H = \pi \sqrt{\frac{2 K_2 (r_2^2 - r_1^2)}{(1 + \theta)(T_2^2 - T_1^2)(r_2^5 \tan \Phi_2 - r_1^5 \tan \Phi_1)}}$$

The value of H in the southern part of Michigan is about 0.18 and the vertical component is about three times as strong or about 0.54. As the presence of masses of iron in the neighborhood has a considerable effect on the dip of the magnetic field and also on the value of the field, a measurement made in any place with iron masses near by, cannot be assumed as valid for even other parts of the same building. Laboratories for the study of the earth's magnetic field should have all iron excluded from the building materials and from the apparatus except the magnets.

If the angle of dip δ has been found by one of the previous methods, the total value of the earth's magnetic field F is

$$F = \frac{H}{\cos \delta}$$

The bars *N* and *L* shown in Fig. 51 are not used in this experiment.

Magnetic Flux and Permeability. There are a number of excellent methods of determining flux and permeability, of which the following will suffice for the purposes of this work.

Divided Bar Method. The divided bar method assumes that the material under test is in the form of two long iron bars or rods with the ends ground and polished into accurately plane surfaces. One bar, with the polished end upward, is mounted in a long solenoid, the polished end being at the middle of the solenoid. The other bar is placed on top of the first with the polished ends resting one on the other and accurately centered. The upper piece is attached to a spring balance which is used to measure the tension necessary to separate the bars. If the weight of the upper piece is subtracted, the remainder gives the pull. The bars and the solenoid must be long enough to have the magnetic field H at the surfaces in contact practically equal to what it would be in an infinitely long solenoid, for which I is the current in amperes and n the number of turns of wire per centimeter length, otherwise a correction must be made for the ends.

$$H = 0.4\,\pi\,n\,I = 1.2566\,n\,I$$

If the area of the ends of the bar is S sq. cm., and the force in grams (weight) F, the value of gravity g (= 980 about), we get for the flux density B,

$$B = \sqrt{\frac{8\,\pi\,g\,F}{S}} = 156.9\sqrt{\frac{F\ \text{(grams)}}{S\ \text{(sq.cm.)}}}$$

If the pull F is measured in pounds and the area S in square inches, we must allow for the ratio of the units. We then obtain

$$B = 1316\sqrt{\frac{F\ \text{(pounds)}}{S\ \text{(sq. in.)}}}$$

In using the method, the spring balance should be supported in guides and drawn upward gradually by means of a turn-buckle or analogous means. The last reading before the bars separate is the one to be taken. If the bars are rounded at the corners an error will be made because the value of B will be increased at the smaller section to a greater value than back in the rod, as the total flux Φ is spread over a smaller area. The pull will be increased because from the above formula it appears that the pull is proportional to the product SB^2. Therefore avoid rounding the edges. If the surfaces do not fit one another, the air where they do not touch will have a lower permeability and there will be a tendency for some of the flux to escape at the side, thus reducing B and consequently the pull.

To obtain the permeability μ divide B by H. As mentioned earlier the permeability increases as B increases, reaching a maximum for moderate values of B and then falls off rapidly for further increase of B.

A magnetization curve (B, H curve) or a permeability curve (B, μ curve) may be plotted from values obtained for different values of B, H, and μ. A bar of iron which has never previously been magnetized, will behave for small values of H differently from what it will again. For this reason the values of H used should increase gradually from lower to higher values. A bar once magnetized cannot be brought back to its original condition by any process except heating it to the temperature at which it becomes practically unmagnetic and then cooling it again, retempering it if necessary. If it is demagnetized by reversing the direction of the field and reducing the latter to lower values gradually on each reversal, most of the magnetism may be removed. This is supposed to reduce the magnetization of the bar to a set of concentric magnetizations in opposite directions in successive concentric layers. This is not quite equivalent to the irregular chains of molecules in a bar which has never been magnetized. A bar which has been demagnetized by a simple reversal of the field to a value apparently reducing B to zero, results in reversing the outer layer only, making the total flux zero *algebraically* as the sum of two *equal* and *opposite* fluxes in concentric layers.

Divided Ring Method. The divided ring method has the material in the form of a ring which has been cut in two and the opposite surfaces polished. The surfaces should be exactly in the same plane to insure a close fit when the ring is put together again. The pull necessary to separate the ring is twice as much as for one surface; so the total pull, after allowing for the weight of the upper part, should be divided by two before applying the previous formula. The ring is magnetized by a ring solenoid surrounding it. The solenoid is in two parts which separate with the parts of the ring.

Ballistic Method. If the material to be tested is in the form of a very long rod, say, 50 diameters in length, or better in the form of a ring, Fig. 65, with little difference between the outer and the inner radius, surrounded by a solenoid of n turns per cm. length through which the current I amp. passes, the field is $H = 1.2566\ n\ I$. A secondary coil of a small number of turns (of which all or a part only may be used) is wound about the ring and is connected to a ballistic galvanometer whose throw for a known quantity passing is known. The ratio K of quantity to throw may be found by charging a condenser of known capacity C microfarads by a standard cell of e. m. f. E volts, and discharging it through a ballistic galvanometer, producing a deflection d. The constant K is then $K = \frac{E\ C}{d \times 10^6}$. Or the galvanometer constant may be determined by winding a solenoid of n_1 turns per cm. on a core of wood or other material of the same permeability as air, for which μ equals 1. H then equals B, and the flux passing through the core whose area is A_1, the current being I_1, is

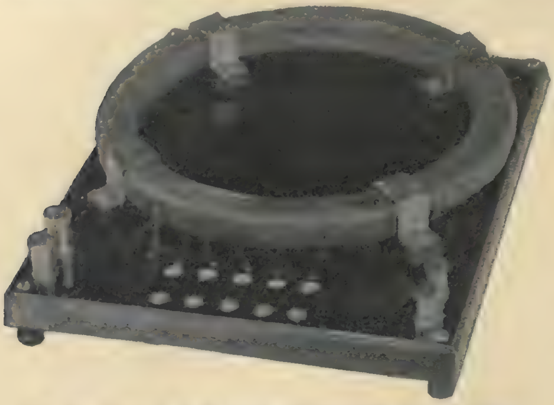


Fig. 65. Iron in Ring Form for Ballistic Measurement.

$$\Phi_1 = 1.2566\ n_1\ A_1\ I_1$$

The total quantity of electricity Q_1 passing through a ballistic galvanometer in series with a secondary circuit of m_1 turns and in a circuit of total resistance R_1, on making or breaking the primary circuit I_1, is

$$Q_1 = \frac{m_1\ \Phi_1}{R_1} = \frac{1.2566\ n_1\ m_1\ A_1\ I_1}{R_1}$$

If the deflection is d_1, the quantity per unit deflection is

$$\frac{Q}{d_1} = \frac{1.2566\ n_1\ m_1\ A_1\ I_1}{R\ d_1} = K$$

K is called the *constant* of the ballistic galvanometer.

If the primary circuit, the solenoid, has n turns per centimeter length, and the secondary circuit a total number m of turns, and the area of the section of the ring is A, and the resistance of the secondary circuit is R, and the deflection is D on reversing the primary circuit of I amperes, we have the flux

$$\Phi = \frac{R\ D\ K}{2\ m}$$

and

$$\mathsf{B} = \frac{\Phi}{A} = \frac{R\ D\ K}{2\ A\ m}$$

The current must be reversed suddenly, some form of commutator being used, otherwise the galvanometer may not feel the full effect. We had previously

$$\mathsf{H} = 1.2566\ n\ I$$

The value of the permeability for any value of H is

$$\mu = \frac{\mathsf{B}}{\mathsf{H}}$$

In using the method the current in the primary is *reversed* because otherwise the residual magnetism will produce a disturbance. If in the experiment the current starts at small values, the disturbing effects of previous magnetization is a minimum. We then insert a high resistance in the circuit at first and note the deflection of the galvanometer on reversing the current. Then increasing the current, the process is repeated. Several reversals should be made at each value of the current until enough observations have been made to ensure an accurate result. The deflection on the first reversal is apt to be different from those following. The B, H curve obtained by this method starts from the origin.

Hysteresis Curves. If instead of reversing the current it is simply changed by a sudden change in the resistance, the deflection will measure the change in B. Starting with no current in the primary and the ring unmagnetized, the circuit is suddenly closed with auxiliary resistance in circuit and the throw of the galvanometer noted as well as the current in the primary. The values of B and H are determined. Next the current is suddenly increased by cutting out part of the resistance and the deflection noted and the ammeter read. The deflection of the galvanometer measures the *increase* of B. The value of B is found by adding the *increase* to the previous value. The current is again increased and the deflection of the galvanometer will measure the increase of B. This is added to the previous total, and so on until the value of B is found for the highest value of H which is to be used. The current, and consequently H, is now reduced by steps, and the deflections of the galvanometer in the opposite direction will measure the decrease of B. To obtain the value of B, these decreases in B are subtracted from the previous value. When the zero value of the current, and consequently of H, is reached, the value of B will still be a considerable amount. The current is now reversed and built up by steps and the deflections will measure the continued decrease of B to zero and its reversal and building up in the reverse direction. This is continued until the maximum reverse value H is reached, equal, we will say, to its previous positive maximum. The current is reduced by steps to zero, reversed, and built up again in the first direction. The deflections measuring changes in B are noted and the total computed by the algebraic sum of all that precede. The sum of all the deflections corresponding to all the steps from the positive maximum to the negative maximum, should equal the sum in the reverse direction. The B, H curve will then make a closed curve for each cycle after the first quarter cycle. The curve for the first quarter cycle starts from the origin and never returns there again. As explained before, the magnetization lags behind the field H, producing the magnetization.

If the curve of B and H, as obtained by this method, is plotted, it is called a *hysteresis curve*, Fig. 61. The curve plotted to scale has an area to 4 π times the energy in ergs expended per cubic centimeter per cycle. Dividing the area by $4 \times \pi \times 10^7$ gives the energy in joules per cycle. If the cycle were run through n times per second, the power in watts would be equal to $\frac{\text{area of curve} \times n}{40{,}000{,}000\ \pi}$ watts expended in each cubic centimeter. This is what happens when an alternating current is used.

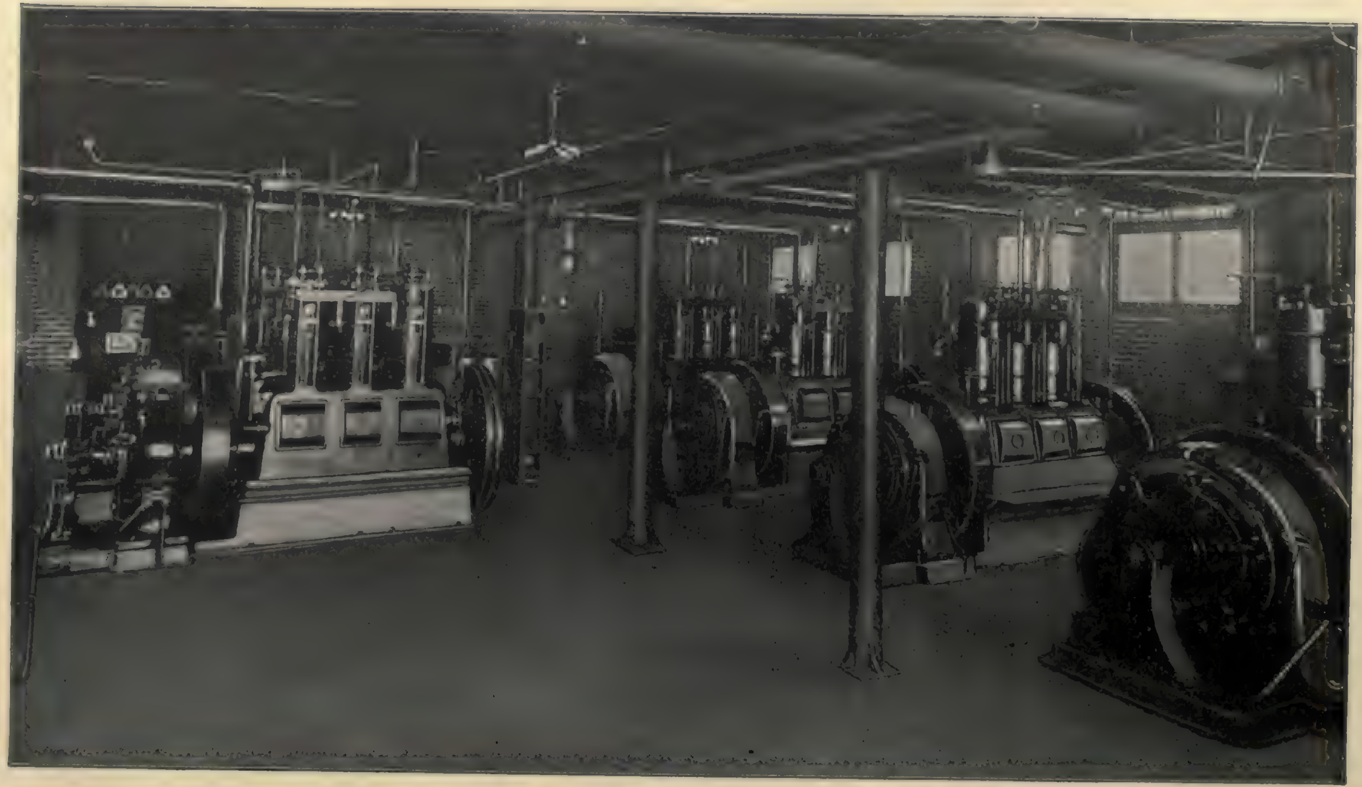
There are two sources of error which may cause trouble in this experiment and which have not been mentioned above. The first is the effect of the current in the primary producing eddy currents in the material of the ring, just as currents are produced in the secondary circuit. In fact, the material of the ring is in itself a secondary circuit of a single turn, and currents in the material of the ring will be parallel to the current in the secondary outside. These eddy currents produce a magnetic field in the ring which opposes the rise of H and B in the ring. Therefore, H in the ring rises slower than the current in the primary coil; and unless the period of the galvanometer is high, some of the effect of the increase of B, which may be slow in increasing, will come too late to be measured by the galvanometer deflection. The other trouble is that if there is any vibration the magnetization may change by small steps one for each shock. This causes the magnetization to creep up or down, depending on whether the field has last been increased or decreased. To avoid the first error it is well to have the material in the form of thin sheets which give little chance for eddy currents, and to avoid the second the ring should rest on a pad of felt or other material which will absorb the vibrations.

Hysteresis Tester. A method of comparing the hysteresis loss of different samples of iron is to compare their effect in dragging the magnetic field when samples are rotated in a constant magnetic field Suppose the sample takes the form of a disk between a pair of field magnet poles. If the disk is at rest the field will produce a flux density B in the disk parallel to H. If the disk is now rotated the residual magnetization will cause the flux to rotate with the disk until the tangential component arrests further rotation of the flux. H and B then make a small angle with one another for very soft iron in the disk, and a proportionately larger angle for harder iron which shows more hysteresis. The turning moment required to rotate the disk will be proportional to the energy expended per cycle. If the poles are free to turn, they will follow the disk. If the poles are kept from rotating by some counter moment due to springs or gravitational action, the displacement of the poles in the direction of rotation of the disk will measure the relative hysteresis loss. If with one sample disk the displacement is twice that produced by another sample, the hysteresis loss is about double. If the hysteresis loss is known for one disk that of the other may be computed.

As the relative twist of B with respect to H is the same for all moderate speeds of rotation, it is not necessary to be careful about the exact speed of rotation. Also it is not necessary that the sample be in the form of a disk. The same relation for samples in the form of bundles of equal size strips will be found to hold true. The absolute angles of twist will be different, but they will have a ratio of equal value.

Professor Ewing has devised a hysteresis tester in which the sample, in the form of a bundle of strips, is rotated by means of a crank and gear train between the poles of a permanent magnet which is mounted on knife edges at a point above its center of gravity. The magnet follows the rotating bundle until the gravitational force gives an equal torque in the opposite direction.

If the sample is in the form of a solid bar, eddy currents of considerable magnitude may be produced which will complicate the results and introduce more or less uncertainty. Moreover, the eddy currents will be greater at higher than at lower rates of rotation, thus introducing different corrections at different speeds. For these reasons the bundle must be well laminated to obtain reliable results.



WALRATH GAS ENGINES DIRECT CONNECTED TO GENERATORS
In Diamond Light & Power Company's Plant, Pittsburg

ELECTRIC LIGHTING

HISTORY AND DEVELOPMENT

The history of electric lighting as a commercial proposition begins with the invention of the Gramme dynamo, by Z. J. Gramme, in 1870, together with the introduction of the Jablochkoff candle or light, which was first announced to the public in 1876, and which formed a feature of the International Exposition at Paris in 1878. Up to this time, the electric light was known to but few investigators, one of the earliest being Sir Humphrey Davy who, in 1810, produced the first arc of any great magnitude. It was then called the *voltaic arc,* and resulted from the use of two wood charcoal pencils as electrodes and a powerful battery of voltaic cells as a source of current.

From 1840 to 1859, many patents were taken out on arc lamps, most of them operated by clockwork, but these were not successful, due chiefly to the lack of a suitable source of current, since all depended on primary cells for their power. The interest in this form of light died down about 1859, and nothing further was attempted until the advent of the Gramme dynamo.

The incandescent lamp was but a piece of laboratory apparatus up to 1878, at which time Edison produced a lamp using a platinum spiral in a vacuum, as a source of light, the platinum being rendered incandescent by the passage of an electric current through it. The first successful carbon filament was made in 1879, this filament being formed from strips of bamboo. The names of Edison and Swan are intimately connected with these early experiments.

From this time on, the development of electric lighting has been very rapid, and the consumption of incandescent lamps alone has reached several millions each year. When we compare the small amount of lighting done by means of electricity twenty-five years ago with the enormous extent of lighting systems and the numerous applications of electric illumination as they are to-day, the growth and development of the art is seen to be very great, and the value of a study of this subject may be readily appreciated. While in many

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cases electricity is not the cheapest source of power for illumination, its admirable qualities and convenience of operation make it by far the most desirable.

CLASSIFICATION

The subject of electric lighting may be classified as follows:

1. The type of lamps used.
2. The methods of distributing power to the lamps.
3. The use made of the light, or its application.
4. Photometry and lamp testing.

The types of lamps used may be subdivided into:

1. Incandescent lamps: Carbon, metallic filament, Nernst.
2. Special lamps: Exhausted bulb without filament, such as the Cooper-Hewitt lamp and Moore tube lamp.
3. Arc lamps: Ordinary carbon, flaming arc.

INCANDESCENT LAMPS

The *incandescent lamp* is by far the most common type of lamp used, and the principle of its operation is as follows:

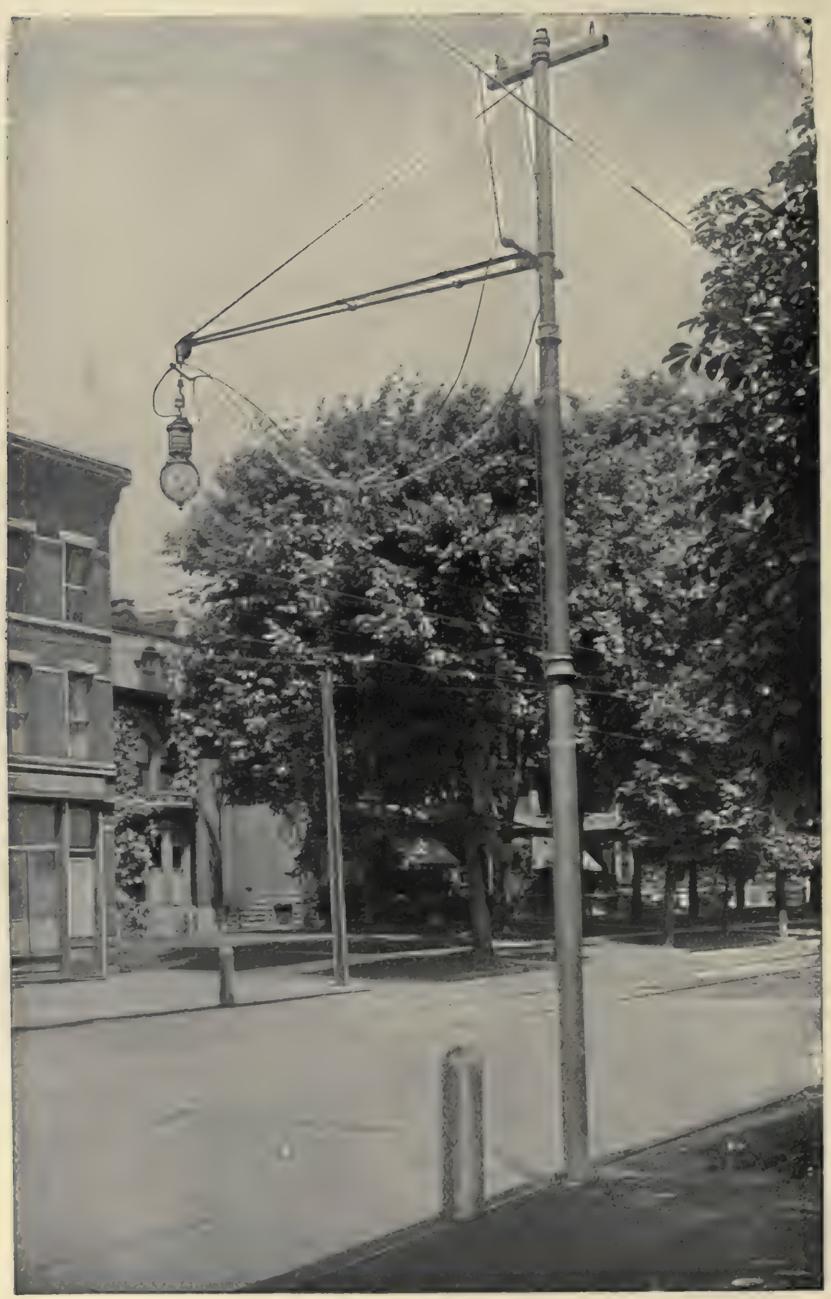
If a current I is sent through a conductor whose resistance is R, for a time t, the conductor is heated, and the heat generated = $I^2R\ t$, $I^2R\ t$ representing joules or watt-seconds.

If the current, material, and conditions are so chosen that the substance may be heated in this way until it gives out light, becomes incandescent, and does not deteriorate too rapidly, we have an incandescent lamp. Carbon was the first successful material to be chosen for this conductor and for ordinary lamps it is formed into a small thread or filament. Very recently metallic filament lamps have been introduced commercially with great success but the carbon incandescent lamp will continue to be used for some time, especially in the low candle-power units operated at commercial voltages. Carbon is a successful material for two reasons:

1. The material must be capable of standing a very high temperature, 1,280° to 1,330° C., or even higher.

2. It must be a conductor of electricity with a fairly high resistance.

Platinum was used in an early stage of the development, but, as we shall see, its temperature cannot be maintained at a value high enough to make the lamp as efficient as when carbon, or a metal



MAST SUSPENSION OF ARC LAMPS.

General Electric Company.

having a melting point higher than that of platinum, is used. Nearly all attempts to substitute another substance in place of carbon have failed until recently, and the few lamps which are entirely or partially successful will be treated later. The nature of the carbon employed in incandescent lamps has, however, been much improved over the first forms, and owing to the still very great importance of this lamp, the method of manufacture will be considered.

Manufacture of Carbon Incandescent Lamps. *Preparation of the Filament.* Cellulose, a chemical compound rich in carbon, is prepared by treating absorbent cotton with zinc chloride in proper proportions to form a uniform, gelatine-like mass. It is customary to stir this under a partial vacuum in order to remove bubbles of air which might be contained in it and destroy its uniformity. This material is then forced, "squirted," through steel dies into alcohol, the alcohol serving to harden the soft, transparent threads. These threads are then thoroughly washed to remove all trace of the zinc chloride, dried, cut to the desired lengths, wound on forms, and carbonized by heating to a high temperature away from air. During carbonization, the cellulose is transformed into pure carbon, the volatile matter being driven off by the high temperature to which the filaments are subjected. The material becomes hard and stiff, assuming a permanent form, shrinking in both length and diameter—the form being specially constructed so as to allow for this shrinkage. The forms are made of carbon blocks which are placed in plumbago crucibles and packed with powdered carbon. The crucibles, which are covered with loosely fitting carbon covers, are gradually brought to a white heat, at which temperature the cellulose is changed to carbon, and then allowed to cool. After cooling, the filaments are removed, measured, and inspected, and the few defective ones discarded.

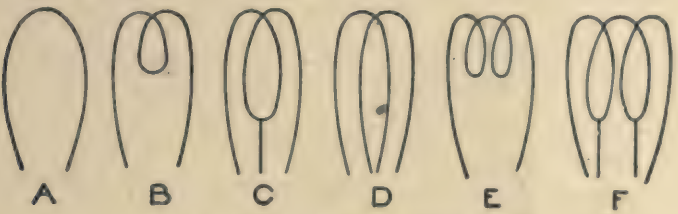


Fig. 1. Forms of Filaments now in Use.

In the early days, these filaments were made of cardboard or bamboo, and later, of thread treated with sulphuric acid.

A few of the shapes of filaments now in use are shown in Fig. 1, the different shapes giving a slightly different distribution of light. As here shown they are designated as follows: A, U-shaped; B, single-curl; C, single-curl anchored; D, double-loop; E, double-curl; F, double-curl anchored.

Mounting the Filament. After carbonization, the filaments are mounted or joined to wires leading into the globe or bulb. These wires are made of platinum—platinum being the only substance, so far as known, that expands and contracts the same as glass, with change in temperature and which, at the same time, will not be melted by the heat developed in the carbon. Since the bulb must remain air-tight, a substance expanding at a different rate from the glass cannot be used. Several methods of fastening the filament to the *leading in* wires have been used, such as forming a socket in the end of the wire, inserting the filament, and then squeezing the socket tightly against the carbon; and the use of tiny bolts when cardboard filaments were used; but the pasted joint is now used almost exclusively. Finely powdered carbon is mixed with some adhesive compound, such as molasses, and this mixture is used as a paste for fastening the carbon to the platinum. Later, when current is sent through the joint, the volatile matter is driven off and only the carbon remains. This makes a cheap and, at the same time, a very efficient joint.

Flashing. Filaments, prepared and mounted in the manner just described, are fairly uniform in resistance, but it has been found that their quality may be much improved and their resistance very closely regulated by depositing a layer of carbon on the outside of the filament by the process of *flashing.* By flashing is meant heating the filament to a high temperature when immersed in a hydrocarbon gas, such as gasoline vapor, under partial vacuum. Current is passed through the filament in this process to accomplish the heating. Gas is used, rather than a liquid, to prevent too heavy a deposit of the carbon. Coal gas is not recommended because the carbon, when deposited from this, has a dull black appearance. The effects of flashing are as follows:

1. The diameter of the filament is increased by the deposited carbon and hence its resistance is decreased. The process must be

discontinued when the desired resistance is reached. Any little irregularities in the filament will be eliminated since the smaller sections, having the greater resistance, will become hotter than the remainder of the filament and the carbon is deposited more rapidly at these points.

2. The character of the surface is changed from a dull black and comparatively soft nature to a bright gray coating which is much harder and which increases the life and efficiency of the filament.

Exhausting. After flashing, the filament is sealed in the bulb and the air exhausted through the tube *A* in Fig. 2, which shows the lamp in different stages of its manufacture. The exhaustion is accomplished by means of mechanical air pumps, supplemented by Sprengle or mercury pumps and chemicals. Since the degree of exhaustion must be high, the bulb should be heated during the process so as to drive off any gas which may cling to the glass. When chemicals are used, as is now almost universally the case, the chemical is placed in the tube *A* and, when heated, serves to take up much of the remaining gas. Exhaustion is necessary for several reasons:

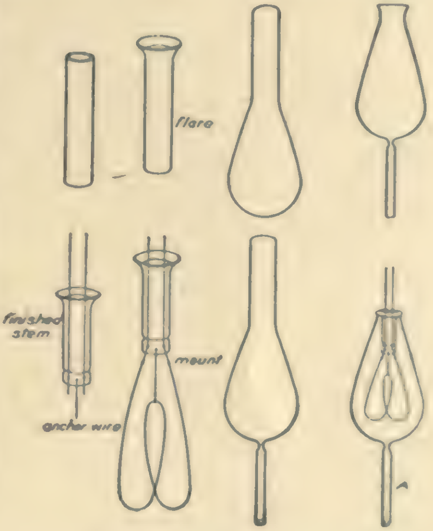


Fig. 2. Different Stages in Lamp Manufacture.

1. To avoid oxidization of the filament.
2. To reduce the heat conveyed to the globe.
3. To prevent wear on the filament due to currents or eddies in the gas.

After exhausting, the tube *A* is sealed off and the lamp completed for testing by attaching the base by means of plaster of Paris. Fig. 3 shows some of the forms of completed incandescent lamps.

Voltage and Candle-Power. Incandescent lamps of the carbon type vary in size from the miniature battery and candelabra lamps to those of several hundred candle-power, though the latter are very seldom used. The more common values for the candle-power are

8, 16, 25, 32, and 50, the choice of candle-power depending on the use to be made of the lamp.

The voltage will vary depending on the method of distribution of the power. For what is known as *parallel distribution,* 110 or 220 volts are generally used. For the higher values of the voltage, long and slender filaments must be used, if the candle-power is to be low; and lamps of less than 16 candle-power for 220-volt circuits are not practical, owing to difficulty in manufacture. For series distribution, a low voltage and higher current is used, hence the filaments may be quite heavy. Battery lamps operate on from 4 to 24 volts, but the vast majority of lamps for general illumination are operated at or about 110 volts.

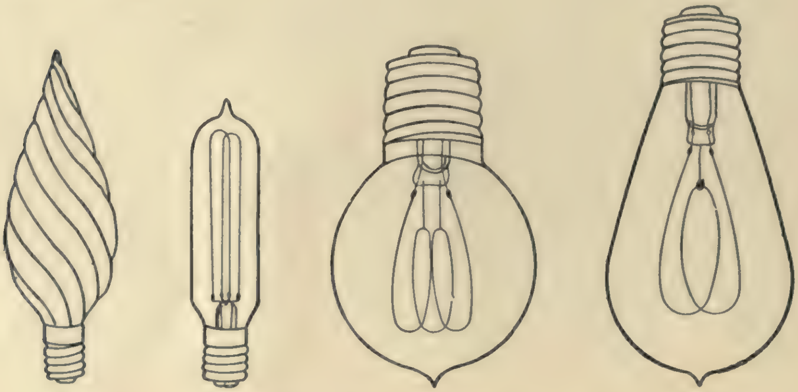


Fig. 3. Several Forms of Completed Lamps.

Efficiency. By the efficiency of an incandescent lamp is meant the power required at the lamp terminals per candle-power of light given. Thus, if a lamp giving an average horizontal candle-power of 16 consumes $\frac{1}{2}$ an ampere at 112 volts, the total number of watts consumed will be $112 \times \frac{1}{2} = 56$, and the watts per candle-power will be $56 \div 16 = 3.5$. The efficiency of such a lamp is said to be 3.5 watts per candle-power, or simply watts per candle. *Watts economy* is sometimes used for *efficiency.*

The efficiency of a lamp depends on the temperature at which the filament is run. In the ordinary lamp this temperature is between 1,280° and 1,330° C, and the curve in Fig. 4 shows the increase of efficiency with the increase of temperature. The temperature attained by a filament depends on the rate at which heat is radiated and the amount of power supplied. The rate of radiation of heat is proportional to the area of the filament, the elevation in temperature, and the emissivity of the surface.

By emissivity is meant the number of heat units emitted from unit surface per degree rise in temperature above that of surrounding bodies. The bright surface of a flashed filament has a lower emissivity than the dull surface of an unheated filament, hence less energy is lost in heat radiation and the efficiency of the filament is increased.

As soon as incandescence is reached, the illumination increases much more rapidly than the emission of heat, hence the increase in efficiency shown in Fig. 4. Were it not for the rapid disintegration of the carbon at high temperature, an efficiency higher than 3.1 watts could be obtained.

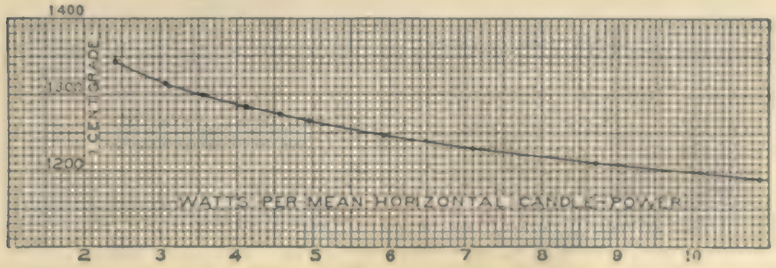


Fig. 4. Efficiency Curve for Incandescent Lamp.

By a special treatment of the carbon filaments, the nature of the carbon is so changed that the filaments may be run at a higher temperature and the lamps still have a life comparable to that of the 3.1-watt lamp. Lamps using these special carbon filaments are known as *gem metallized filament lamps*, or merely as *gem lamps*, and they will be described more fully later.

Relation of Life to Efficiency. *Ordinary Carbon Lamp.* By the useful life of a lamp is meant the length of time a lamp will burn before its candle-power has decreased to such a value that it would be more economical to replace the lamp with a new one than to continue to use it at its decreased value. A decrease to 80% of the initial candle-power of carbon lamps is now taken as the point at which a lamp should be replaced, and the normal life of a lamp is in the neighborhood of 800 hours. To obtain the most economical results, such lamps should always be replaced at the end of their useful life.

In Table I are given values of efficiency and life of a 3.5-watt, 110-volt carbon lamp for various voltages impressed on the lamp. These values are plotted in Fig. 5. The curves show that a 3% increase of voltage on the lamp reduces the life by one-half, while an increase of 6% causes the useful life to fall to one-third its normal value. The effect is even greater when 3.1-watt lamps are used, but not so great with 4-watt lamps. From this we see that the regulation of the voltage used on the system must be very good if high efficiency lamps are to be used, and this regulation will determine the efficiency of the lamp to be installed.

Selection of Lamps. *Ordinary Carbon Type.* Lamps taking 3.1 watts per candle-power will give satisfaction only when the regulation of voltage is the best—practically a constant voltage maintained at the normal voltage of the lamp.

TABLE I

Effects of Change in Voltage

Standard 3.5-Watt Lamp

Voltage Per Cent. of Normal	Candle-Power Per Cent. of Normal	Watts Per Candle-Power	Life Per Cent. of Normal	Deterioration Per Cent. of Normal
90	53	5.36		
91	56	5.09		
92	61	4.85		
93	65	4.63		
94	69	4.44	394	25
95	73	4.26	310	32
96	78	4.09	247	44
97	83	3.93	195	51
98	88	3.78	153	65
99	94	3.64	126	79
100	100	3.5	100	100
101	106	3.38	84	118
102	111	3.27	68	146
103	116	3.16	58	173
104	123	3.05	47	211
105	129	2.95	39	253
106	137	2.85	31	316
107	143	2.76	26	380
108	152	2.68	21	474
109	159	2.60	17	575
110	167	2.53	16	637

Lamps of 3.5 watts per candle-power should be used when the regulation is fair, say with a maximum variation of 2% from the normal voltage.

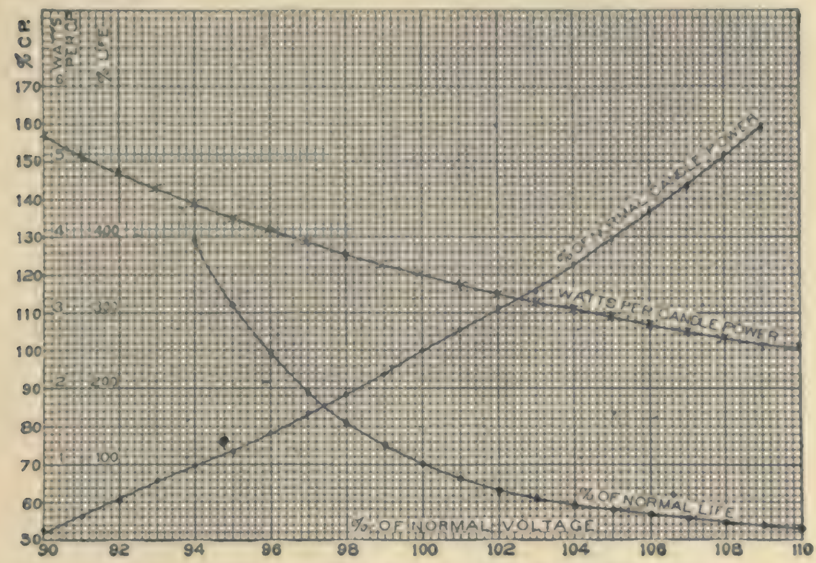


Fig. 5. Curves of Efficiency and Life of Carbon Filament Lamps.

Lamps of 4 watts per candle-power should be installed when the regulation is poor. These values are for 110-volt lamps. A 220-volt lamp should have a lower efficiency to give a long life. This is on account of the fact that, for the same candle-power, the 220-volt lamp must be constructed with a filament which is long and slender compared to that of the 110-volt lamp, and if such a filament is run at a high temperature its life is short. The 220-volt lamp is used to some considerable extent abroad but it is not employed extensively in the United States. It is customary to operate such lamps at an efficiency of about 4 watts per candle-power.

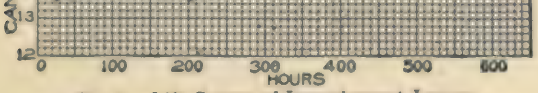


Fig. 6. Life Curves of Incandescent Lamps.

Lamps should always be renewed at the end of their useful life, this point being termed the *smashing-point*, as it is cheaper to replace the lamp than to run it at the reduced candle-power. Some recommend running these lamps at a higher voltage, but that means at a reduced life, and it is not good practice to do this.

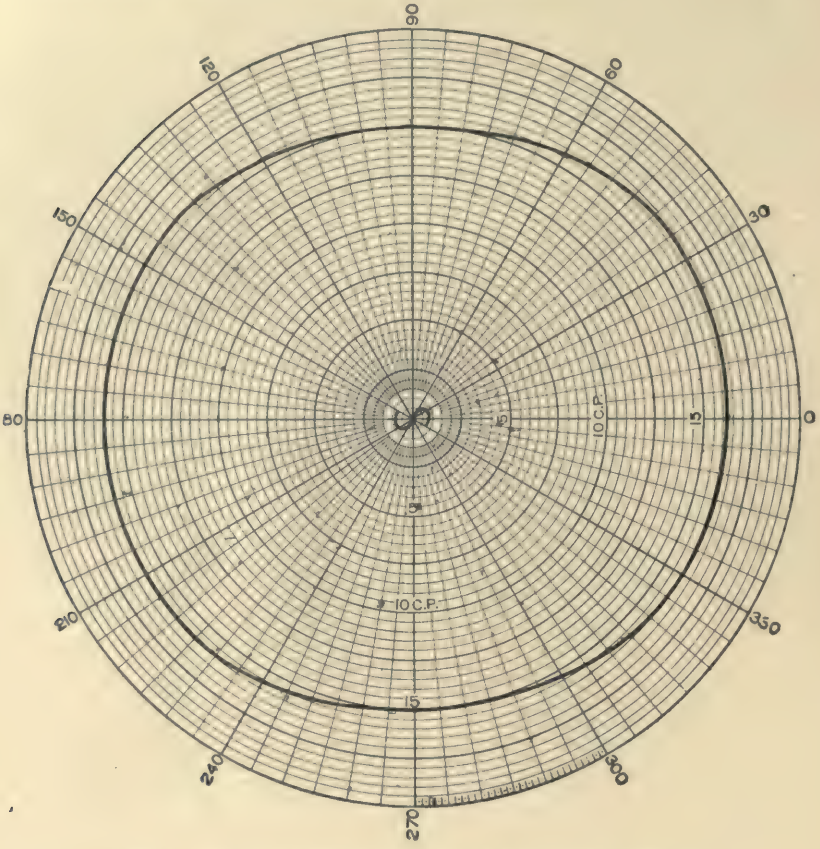


Fig. 7. Horizontal Distribution Curve for Single-Loop Filament.

Fig. 6 shows the life curves of a series of incandescent lamps. These curves show that there is an increase in the candle-power of some of the lamps during the first 100 hours, followed by a period during which the value is fairly constant, after which the light given by the lamp is gradually reduced to about 80% of the initial candle-power.

Distribution of Light. In Fig. 1 are shown various forms of filaments used in incandescent lamps, and Figs. 7 and 8 show the distribution of light from a single-loop filament of cylindrical cross-section. Fig. 7 shows the distribution of light in a horizontal plane, the lamp being mounted in a vertical position, and Fig. 8 shows the distribution in a vertical plane. By changing the shape of the filament, the light distribution is varied. A mean of the readings taken in the horizontal plane forms the *mean horizontal candle-power*, and this candle-power rating is the one generally assumed for the ordinary incandescent lamp. A mean of the readings taken in a vertical plane gives us the mean vertical candle-power, but this value is of little use.

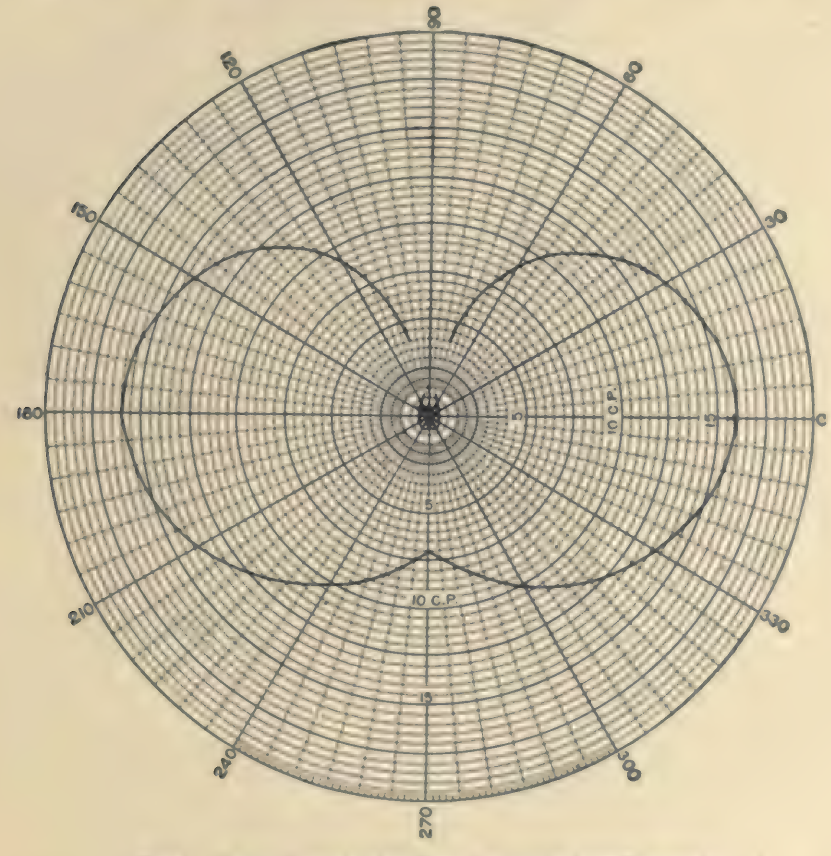


Fig. 8. Vertical Distribution Curve for Single-Loop Filament.

Mean Spherical Candle-Power. When comparing lamps which give an entirely different light distribution, the mean horizontal candle-power does not form a proper basis for such comparison, and the mean spherical or the mean hemispherical candle-power is used instead. By *mean spherical candle-power* is meant a mean value of the light taken in all directions. The methods for determining this will be taken up under *photometry.* The mean hemispherical candle-power has reference, usually, to the light given out below the horizontal plane.

The Gem Metallized Filament Lamp. When the incandescent lamp was first well established commercially, the useful life of a unit, when operated at 3.1 watts per candle, was about 200 hours. The improvements in the process of manufacture have been continuous from that time until now, and the useful life of a lamp operated at that efficiency to-day is in the neighborhood of 500 hours. Experiments in the treatment of the carbon filament have led to the introduction of the *gem metallized filament lamp.* This lamp should not be confused with the metallic filament lamps, to be described later, because the material used is carbon, not a metal. As a result of special treatment the carbon filament assumes many of the characteristics of a metallic conductor, hence the term *metallized filament.* The word *graphitized* has been proposed in place of metallized.

TABLE II

*** Data on the Gem Metallized Filament Lamp**

Watts	Horizontal C. P.	Watts per Candle	†Spherical Reduction Factor	§ Useful Life
40	16	2.5	.816	450 hrs.
50	20	2.5	.825	450 "
80	32	2.5	.816	450 "
100	40	2.5	‡	460 "
125	50	2.5	‡	450 "
187.5	75	2.5	‡	450 "
250	100	2.5	‡	450 "

* These lamps are normally rated at three voltages, 114, 112, and 110 volts, but data referring to the highest voltage only are given.

† By spherical reduction factor is meant the factor by which the horizontal candle-power must be multiplied to obtain the mean spherical candle-power.

‡ The larger units are almost invariably used with reflectors, hence no spherical reduction factor is given.

§ The life of the lamps when operated at the lower voltage is increased to about 950 hours, and the efficiency is changed to 2.83 watts per candle.

When a filament, as treated in the ordinary manner, is run at a high temperature in a lamp there is no improvement of the filament, but it was discovered that, if the treated filaments were subjected to the extremely high temperature of the electric resistance furnace—3,000 to 3,700 degrees C.—at atmospheric pressure, the physical nature of the carbon was changed and the resulting filament could be operated at a higher temperature in the lamp and a higher efficiency, and still maintain a life comparable to that of a 3.1-watt lamp. This special heating of the filament, which is applied to the base filament before it is flashed, as well as to the treated filament, causes the cold resistance of the carbon to be very materially decreased and the filament, as used in the lamp, has a positive temperature coefficient—rise in resistance with rise in temperature—a desirable feature from the standpoint of voltage regulation of the circuit from which the lamps are operated. The high temperature also results in the driving off of considerable of the material which, in the ordinary lamp, causes the globe to blacken after the lamp has been in use for some time. The blackening of the bulb is responsible to a considerable degree

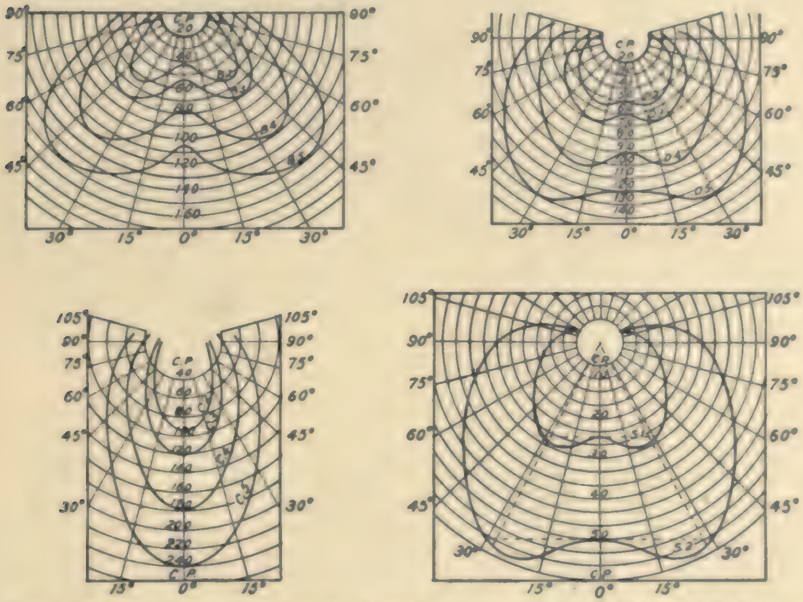


Fig. 9. Typical Distribution Curves of Gem Lamp with Different Types of Reflectors.

for the decrease in candle-power of the incandescent lamp. The metallized filament lamp is operated at an efficiency of 2.5 watts per candle with a useful life of about 500 hours. The change in candle-power with change in voltage is less than in the ordinary lamp on account of the positive temperature coefficient of the filament. These lamps are not manufactured for very low candle-powers, owing to the difficulty of treating very slender filaments, but they are made in sizes consuming from 40 to 250 watts. Table II gives some useful information in connection with metallic filament lamps. The filaments are made in a variety of shapes and the distribution curves are usually modified in practice by the use of shades and reflectors. The general appearance of the lamp does not differ from that of the ordinary carbon lamp. Fig. 9 shows typical distribution curves of the metallized filament lamp as it is installed in practice.

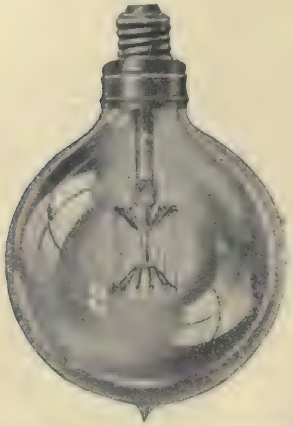


Fig. 10. Round Bulb Tantalum Lamp.

Metallic Filament Lamps. *The Tantalum Lamp.* The first of the metallic filament lamps to be introduced to any considerable extent commercially was the tantalum lamp. Dr. Bolton of the Siemens & Halske Company first discovered the methods of obtaining the pure metal tantalum. This metal is rendered ductile and drawn into slender filaments for incandescent lamps. Tantalum has a high tensile strength and high melting point, and tantalum filaments are operated at temperatures much higher than those used with the carbon filament lamp. On account of the comparatively low specific resistance of this material the filaments for 110-volt lamps must be long and slender, and this necessitates a special form of support. Figs. 10, 11, and 12 show some interesting views of the tantalum lamp and the filament. This lamp is operated at the efficiency of 2 watts per

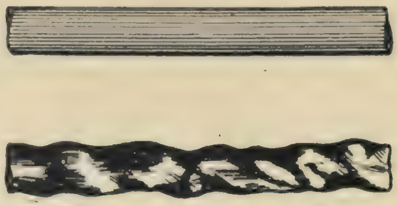


Fig. 11. Tantalum Filament Before and After 1,000 Hours' Use.

candle-power, with a life comparable to that of the ordinary lamp. By special treatment it is possible to increase the resistance of the filaments so that they may be shorter and heavier than those used in the first of the tantalum lamps. It should be noted that the life of this type of lamp on alternating-current circuits is somewhat uncertain; it is much more satisfactory for operation on direct-current circuits. Tables III and IV give some general data on the tantalum lamp, and Figs. 13 and 14 show typical distribution curves for the units as installed at present.

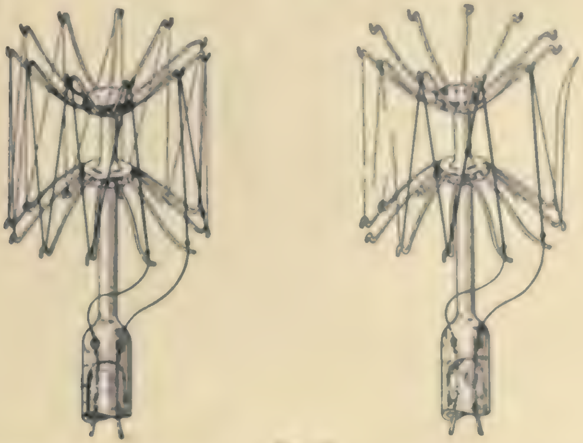


Fig. 12.

Appearance of Filament After Having Been Used.

Filament Frame Showing Broken Filament.

TABLE III

Data on Tantalum Lamp

GENERAL ELECTRIC CO., MFTRS.

Size of Bulb		Diameter of Bulb in Inches	Estimated Life	
Regular	Round		on A. C.	on D. C.
40 watt		$2\frac{5}{16}$	350	800
50 "		$2\frac{5}{16}$	350	800
80 "		$3\frac{1}{8}$	400	800
	40 watt	$3\frac{3}{4}$	350	800
	80 "	5	400	800

TABLE IV

Data on the Life of a 25-C. P. Unit

No. of Hours Burned	Candle-Power	Watts per Candle
0	19.8	2.17
25	23.6	1.865
50	23.1	1.90
125	22.3	1.98
225	22.4	1.96
350	22.3	1.97
450	22.2	1.98
550	21.2	2.05
650	19.6	2.20

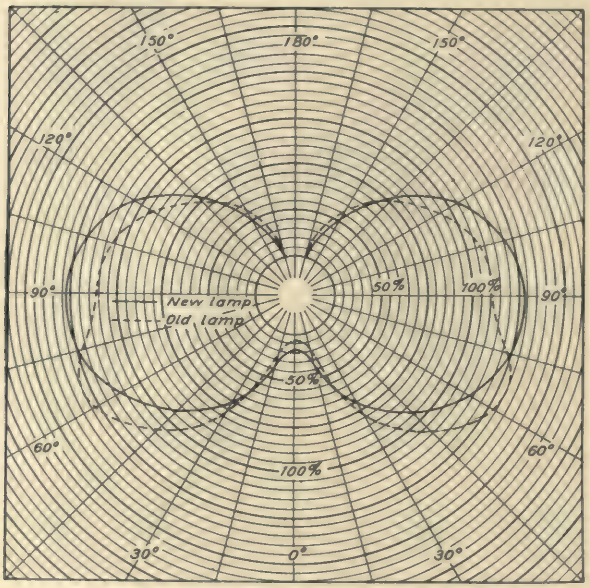


Fig. 13. Vertical Distribution Curve Without Reflector.

The Tungsten Lamp. Following closely upon the development of the tantalum lamp came the tungsten lamp. Tungsten possesses a very high melting point and an indirect method is employed in forming filaments for incandescent lamps. There are several of these methods in use. In one method a fine carbon filament is flashed in an atmosphere of tungsten oxychloride mixed with just the proper proportion of hydrogen, in which case the filament gradually changes to one of tungsten. A second method consists of the use of powdered tungsten and some binding material, sometimes organic and in other cases metallic. The powdered tungsten is mixed with the binding material, the paste squirted into filaments, and the binding material is then expelled, usually by the aid of heat. Another method of manufacture consists of securing tungsten in colloidal form, squirting it

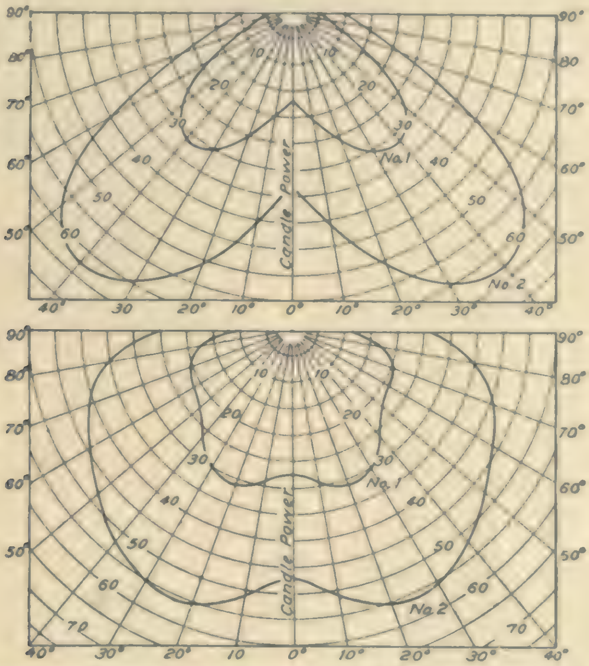


Fig. 14. Distribution Curves for Tantalum Lamp. No. 1, 40 Watts; No. 2, 80 Watts

into filaments, and then changing them to the metallic form by passing electric current through the filaments.

The tungsten lamp has the highest efficiency of any of the commercial forms of metallic filament lamps now in use, about 1.25 watts per candle-power when operated so as to give a normal life, and lamps for 110-volt service and consuming but 40 watts have recently been put on the market. A 25-watt lamp for this same voltage appears to be a possibility. The units introduced at first were of high candle-power because of the difficulty of manufacturing the slender filaments required for the low candle-power lamps.

The advantages of these metals, tantalum and tungsten, for incandescent lamps are in the improved efficiency of the lamps and the good quality of the light, white or nearly white in both cases. In either case the change in candle-power with change in voltage is less than the corresponding change in an ordinary carbon lamp. The disadvantage lies in the fact that the filaments must be made long and slender, and hence are fragile, for low candle-power units to be used on commercial voltages. In some cases tungsten lamps are constructed for lower voltages and are used on commercial circuits through the agency of small step-down transformers. Improvements in the process of manufacture of filaments and of the method of their support have resulted in the construction of 110-volt lamps for candle-powers lower than was once thought possible. Figs. 15 and 16 show the appearance of the tungsten lamp, and Figs. 17 and 18 give some

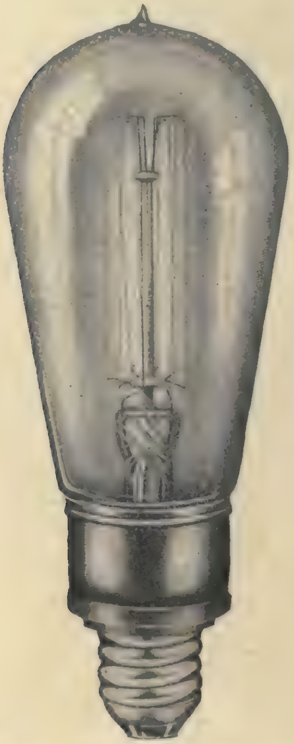


Fig. 15. Multiple Tungsten Lamp.

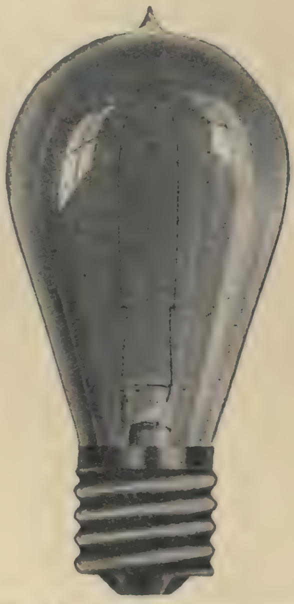
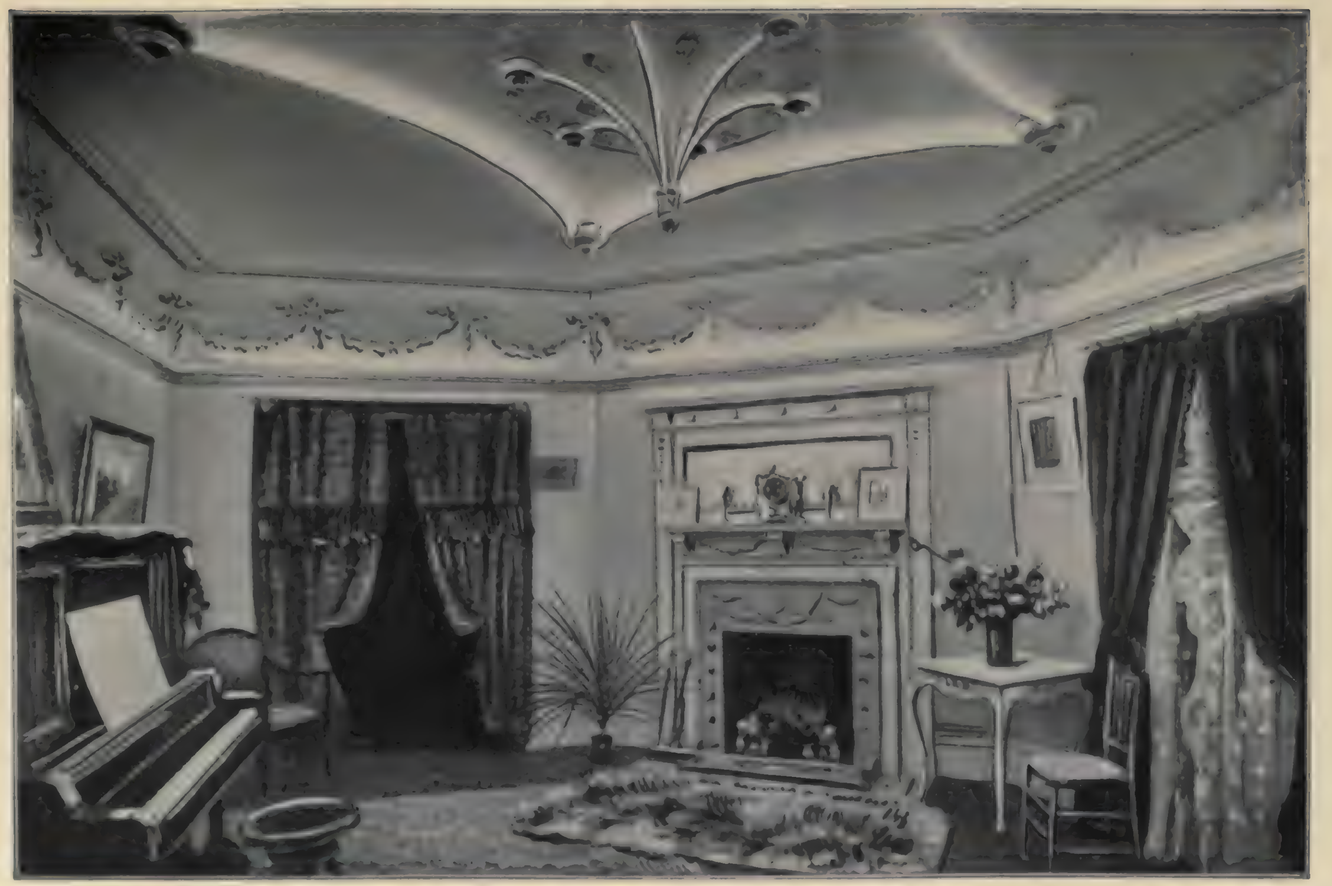


Fig. 16. Series Tungsten Lamp.



MOORE VACUUM-TUBE LIGHT.

Designed to Actually Imitate Daylight with a Better Efficiency than the Incandescent Lamp.

typical distribution curves. Tables V and VI give data on this lamp as it is manufactured at present. One very considerable application of the tungsten lamp is to incandescent street lighting on series circuits, in which case the lamp may be made for a low voltage across its terminals and the filament may be made comparatively short and heavy. The tungsten lamp is also being introduced as a low voltage battery lamp.

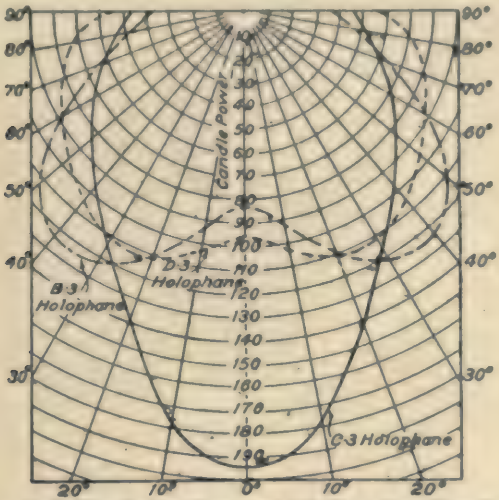


Fig. 17. C. P. Distribution Curves of 100-Watt Gen. Elec. Tungsten Incandescent Units with B-3, C-3, and D-3 Holophanes.

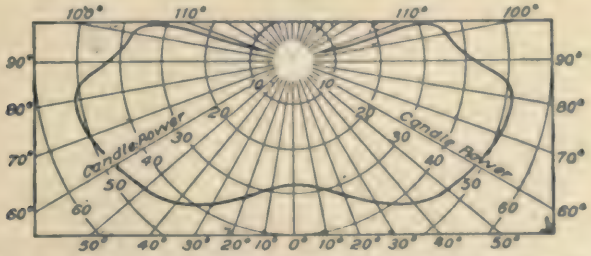


Fig. 18. Candle-Power Distribution Given with 40 c. p Gen. Elec. Tungsten Series Lamp and Radial Wave Reflector.

The Just lamp, the Z lamp, the Osram lamp, the Zircon-Wolfram lamp, the Osmin lamp, etc., are all tungsten lamps, the filaments being prepared by some of the general methods already described or modifications of them.

TABLE V

Tungsten Lamps

MULTIPLE

Watts	Volts	Candle-Power	Watts per C. P.	Tip Candle-Power	Spherical Reduction Factor
40	100 to 125	32	1.25	5	76.3
60		40	1.25	5.6	76.3

TABLE VI

Tungsten Lamps

SERIES

Amperes	Volts	Candle-Power	Watts per C. P.
4	13.5	40	1.35
	20.25	60	
5.5	9.8	40	1.35
	14.7	60	
6.6	8.2	40	1.35
	12.3	60	
7.5	7.2	40	1.35
	10.8	60	

The Osmium Lamp. Very efficient incandescent lamps have been constructed using osmium for the filament. An indirect method is resorted to in the formation of these filaments. Osmium lamps have not been successful for commercial voltages because the filament is too fragile if it is made to have a high resistance, so these lamps must be operated in series or through the agency of reducing transformers if they are to be applied to 110-volt circuits. At 25 volts, lamps are constructed giving an efficiency of about 1.5 watts per candle-power with a life comparable to that of a 3.5-watt carbon lamp. Owing to the introduction of the tungsten lamp, the osmium lamp will probably never be used to any great extent.

Other Metallic Filament Lamps. Table VII gives the melting points of several metals which are highly refractory and those already mentioned are not the only ones which have been successfully used in incandescent lamps. Titanium, zirconium, iridium, etc., have been successfully employed, but the tantalum and tungsten lamps are the only ones which are used to any extent in the United States.

TABLE VII

Melting Point of Some Metals

Metal	Approximate Melting Point in Degrees C
Tungsten	3080 3200
Titanium	3000
Tantalum	2900
Osmium	2500
Platinum	1775
Zirconium	1500
Silicon	1200
Carbon (not a metal)	3000

The Helion Lamp. The helion lamp, which gives considerable promise of commercial development, is a compromise between the carbon lamp and the metallic filament lamp. A slender filament of carbon is flashed in a compound of silicon (gaseous state) and a filament composed of a carbon core more or less impregnated with silicon and coated with a metallic layer is formed. The emissivity of such a filament is high, the light is white in color, and the filament is strong. The efficiency of the helion filament as far as it has been developed is higher than that of a carbon filament when operated at the same temperature. At 1,500 degrees C. the efficiency of the helion filament is 2.15 watts per candle-power, while for a carbon filament it is about 3.5 watts per candle-power. Filaments of this type have been made which may be heated to incandescence in open air without immediate destruction. This lamp is not yet on the market.

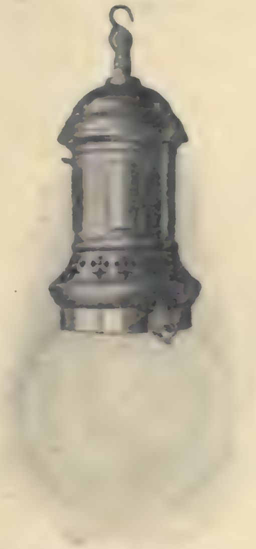


Fig. 19. Westinghouse Nernst Multiple-Glower Lamp.

The Nernst Lamp. The Nernst lamp is still another form of incandescent lamp, several types of which are shown in Figs. 19, 20, 21, and 22. This lamp uses for the incandescent material certain oxides of the rare earths, the oxides being mixed in the form of a paste, then squirted through a die into a string which is subjected to a roasting process forming the filament or *glower* material of the lamp as represented by the lower white line in Fig. 23. The more recent glowers are made hollow instead of solid. The glowers are cut to the desired length and platinum terminals attached. The attachment of these terminals to the glowers is an important process in the manufacture of the lamp. The recent discovery of additional oxides has led to the construction of glowers which show a considerable gain in efficiency over those previously used. The glowers are heated to incandescence in open air, a vacuum not being required.

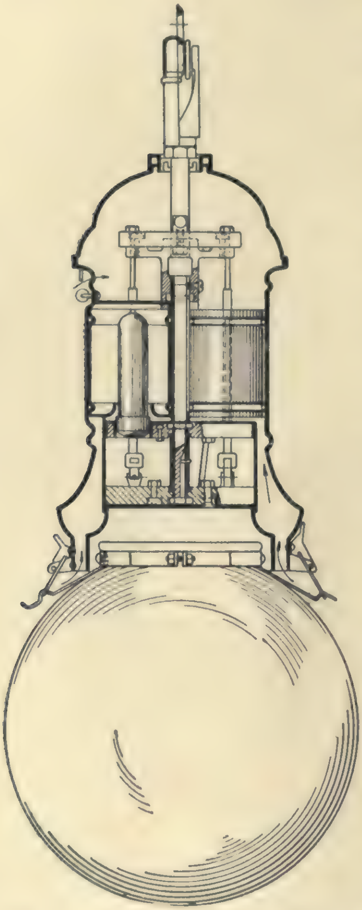


Fig. 20. Sectional View of Multiple-Glower Westinghouse Nernst Lamp.

As the glower is a non-conductor when cold, some form of *heater* is necessary to bring it up to a temperature at which it will conduct. Two forms of heater have been used. One of them consists of a porcelain tube shown just above the glower, Fig. 23, about which a fine platinum wire is wound; the wire is in turn coated with a cement. Two or more of these tubes are mounted directly over the glower, or glowers, and serve as a reflector as well as a heater. The second form of heater consists of a slender rod of refractory material about which a platinum wire is wound, the wire again being covered with a cement. This rod is then formed into a spiral which surrounds the glower in the vertical glower type, or is formed into the *wafer heater,* Fig. 24, now universally employed in the Westinghouse Nernst lamp with horizontal glowers. The wafer heater is bent so that it can be mounted with several sections parallel to the glower or glowers.

The heating device is connected across the circuit when the lamp is first turned on, and it must be cut out of circuit after the glowers become conductors in order to save the energy consumed by the heater and to prolong the life of the heater. The automatic *cut-out* is operated by means of an electromagnet so arranged that current flows through this magnet as soon as the glower becomes a conductor, and contacts in the heater circuit are opened by this magnet. The contacts in the heater circuit are kept normally closed, usually by the force of gravity.

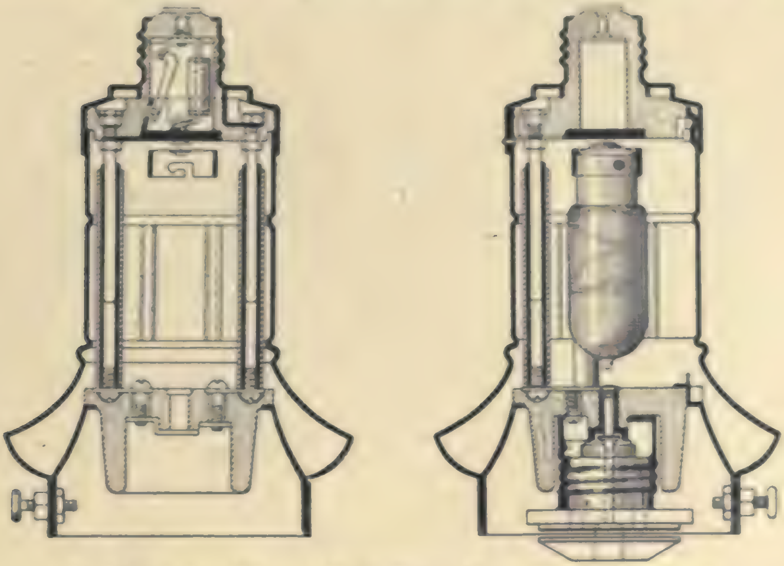


Fig. 21. Sectional Views of Single-Glower Westinghouse Nernst Lamp.

The conductivity of the glower increases with the increase of temperature—the material has a negative temperature coefficient—hence if it were used on a constant potential circuit directly, the current and temperature would continue to rise until the glower was destroyed. To prevent the current

Fig. 22. Westinghouse Nernst Screw Burner.

from increasing beyond the desired value, a *ballast resistance* is used in series with the glower. As is well known, the resistance of iron wire increases quite rapidly with increase in temperature, and the resistance of a fine pure iron wire is so adjusted that the resistance of the combined circuit of the glower and the ballast becomes constant at the desired temperature of the glower. The iron wire must be protected from the air to prevent oxidization and too rapid temperature changes, and, for this reason, it is mounted in a glass bulb filled with hydrogen. Hydrogen has been selected for this purpose because it is an inert gas and conducts the heat from the ballast to the walls of the bulb better than other gases which might be used.

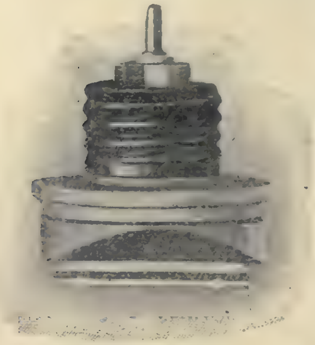


Fig. 23. Westinghouse Nernst Screw Burner with Globe Removed, Showing Glower and Tubular Heater.

All of the parts enumerated, namely, glower, heater, cut-out, and ballast, are mounted in a suitable manner; the smaller lamps have but one glower and are arranged to fit in an incandescent lamp socket, while the larger types are constructed at present with four glowers and are arranged to be supported in special fixtures, or the same as small arc lamps. All parts are mechanically arranged so that renewals may be easily made when necessary and it is not possible to insert a part belonging to one type of lamp into a lamp of a different type.

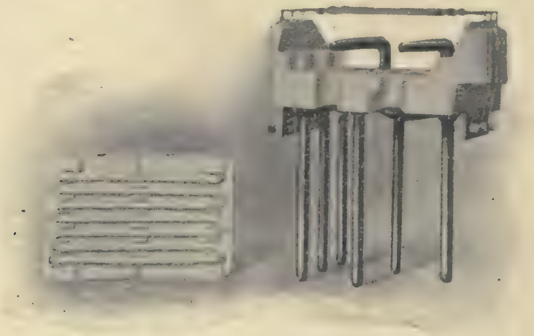


Fig. 24. Wafer Heater and Mounting.

The advantages claimed for the Nernst lamp are: High efficiency; a good color of light; a good distribution of light without the use of reflectors; a long life with low cost of maintenance; and a complete series of sizes of units, thus allowing its adaption to practically all classes of illumination.

The lamp is constructed for both direct- and alternating-current service and for 110 and 220 volts. When the alternating-current lamp is used on a 110-volt circuit a small transformer, commonly called a *converter coil*, Fig. 25, is utilized to raise the voltage at the lamp terminals to about 220 volts.

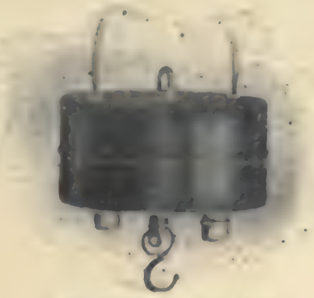


Fig. 25. Converter Coil.

Data on the Nernst lamp in its present form are given in Table VIII, and Figs. 26 and 27 show the form of distribution curves.

TABLE VIII

General Data on the Nernst Lamp

Lamp Rating in Watts	Voltage	Current in Amperes	Max. Candle-Power	Mean Hemispherical c. p.	Watts per M. H. S. c. p. from Test		
66	110	6	74	50	1.38	1-Glower	A.C. or D.C.
88	220	4	105	77	1.2		
110	110 220	1.0 5	131	96.4	1.2		
132	110 220	1.2 6	156	114	1.2		
264	220	1.2	345	231	1.2	2-Glower	A.C. or D.C.
396	220	1.8	528	359	1.15	3-Glower	
528	220	2.4	745	504	1.09	4-Glower	

Comparison of the Different Types of Incandescent Lamps. A direct comparison of the different types of incandescent lamps cannot be made but it is desirable at this time to note the following points: The lamps which are considered commercial in the United States at the present time are the carbon, gem, tantalum, tungsten, and Nernst lamp. The efficiencies ordinarily accepted run in the order given, approximately 3.1, 2.5, 2, 1.25, and 1.2 watts per candle respectively. The figure of 1.2 watts per candle for the Nernst lamp is based upon the mean hemispherical candle-power and it should not be compared directly with the other efficiencies. The color of the light in all of the above cases is suitable for the majority of classes of illumination, the light from the higher efficiency units being somewhat whiter than that from the carbon lamp. All of these lamps are constructed for commercial voltages and for either direct or alternating current. The use of the tantalum lamp on alternating current is not always to be recommended as the service is unsatisfactory in some cases. The minimum size of units for 110 volts is about 4 candle-power for the carbon lamp, 20 candle-power for the metallic filament lamp, and 50 candle-power (mean hemispherical) for the Nernst lamp. Some of the metallic filament lamps are constructed for a consumption of as high as 250 watts, while the largest size of the Nernst lamp uses 528 watts. The light distribution of any of the units is subject to considerable variation through the agency of reflectors, but the Nernst lamp is ordinarily installed without a reflec-

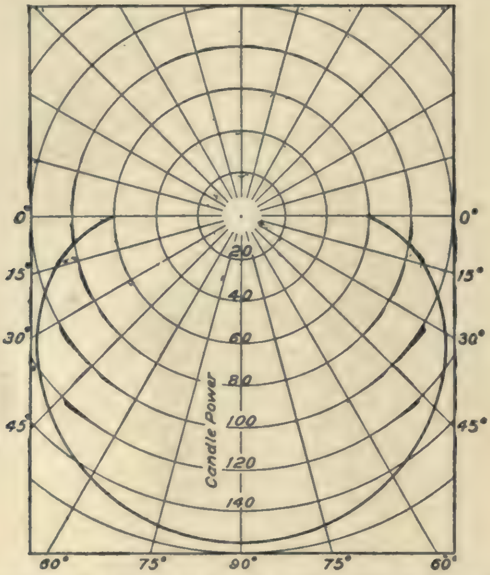


Fig. 26. Distribution Curve of 132-Watt Type Westinghouse Nernst Lamp. Single Glower.

tor. Practically all of the other units of high candle-power use reflectors and only a few of the typical curves of light distribution curves with reflectors have been shown in connection with the description of the lamps. The life of all of the commercial lamps described is considered as satisfactory. The minimum life is seldom less than 500 hours and the useful life is generally between 500 and 1,000 hours. On account of the slender filaments employed in the metallic filament lamps they are not made for low candle-powers at commercial voltages. The introduction of transformers for the purpose of changing the circuit voltage to one suitable for low candle-power units has not become at all general as yet in this country.

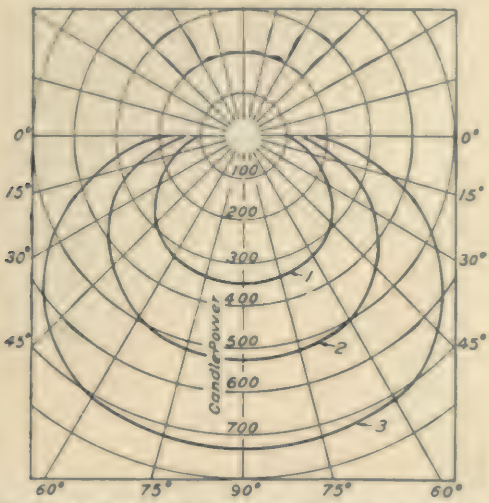


Fig. 27. Distribution of Light from Multiple-Glower Westinghouse Nernst Lamps with 8" Clear Globes. No. 1, 2 Glower; No. 2, 3 Glower; No. 3, 4 Glower.

SPECIAL LAMPS

The Mercury Vapor Lamp. The mercury vapor lamp in this country is put on the market by the Cooper-Hewitt Electric Company and it is being used to a considerable extent for industrial illumination. In this lamp mercury vapor, rendered incandescent by the passage of an electric current through it, is the source of light. In its standard form this lamp consists of a long glass tube from which the air has been carefully exhausted, and which contains a small amount of metallic mercury. The mercury is held in a large bulb at one end of the tube and forms the negative electrode in the direct-current lamp. The other electrode is formed by an iron cup and the connections between the lamp terminals and the electrodes are of platinum where this connection passes through the glass. Fig. 28 gives the general appearance of a standard lamp having the following specifications:

Total watts (110 volts, 3.5 amperes) = 385
Candle-power (M. H. with reflector) = 700
Watts per candle = 0.55
Length of tube, total = 55 in.
Length of light-giving section = 45 in.
Diameter of tube = 1 in.
Height from lowest point of lamp to ceiling plate = 22 in.

For 220-volt service two lamps are connected in series.

The mercury vapor, at the start, may be formed in two ways: First, the lamp may be tipped so that a stream of mercury makes contact between the two electrodes and mercury is vaporized when the stream breaks. Second, by means of a high inductance and a quick break switch, a very high voltage sufficient to pass a current from one electrode to the other through the vacuum, is induced and the conducting vapor is formed. The tilting method of starting is preferred and this tilting is brought about automatically in the more recent types of lamp Fig. 29 shows the connections for automatically starting two lamps in series. A steadying resistance and reactance are connected as shown in this figure.

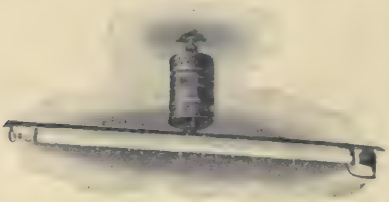


Fig. 28. Cooper-Hewitt Mercury Vapor Lamp.

The mercury vapor lamp is constructed in rather large units, the 55-volt, 3.5-ampere lamp being the smallest standard size. The color of the light emitted is objectionable for some purposes as there is an entire absence of red rays and the light is practically *monochromatic.* The illumination from this type of lamp is excellent where sharp contrast or minute detail is to be brought out, and this fact has led to its introduction for such classes of lighting as silk mills and cotton mills. On account of its color the application of this lamp is limited to the lighting of shops, offices, and drafting rooms, or to display windows where the goods shown will not be changed in appearance by the color of the light. It is used to a considerable extent in photographic work on account of the actinic properties of the light. Special reactances must be provided for a mercury arc lamp operating on single-phase, alternating-current circuits.

The Moore Tube Light. The Moore light makes use of the familiar Geissler tube discharge—discharge of electricity through a vacuum tube—as a source of illumination. The practical application of this discharge to a system of lighting has involved a large amount of consistent research on the part of the inventor and it has now been brought to such a stage that several installations have been made. The system has many interesting features.

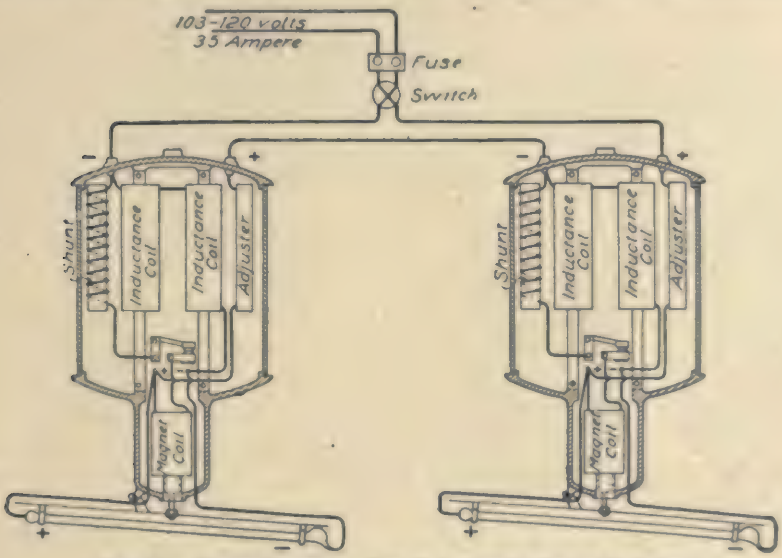


Fig. 29. Wiring Diagram. Two H Automatic Lamps in Series.

In the normal method of installation, a glass tube 1¾ inches in diameter is made up by connecting standard lengths of glass tubing together until the total desired length is reached, and this continuous tube, which forms the source of light when in operation, is mounted in the desired position with respect to the plane of illumination. In many cases the tube forms a large rectangle mounted just beneath the ceiling of the room to be lighted. The tube may be of any reasonable length, actual values running from 40 to 220 feet. In order to provide an electrical discharge through this tube it is customary to lead both ends of the tube to the high tension terminals of a transformer, the low tension side of which may be connected to the alternating-current lighting mains. This transformer is constructed so that the high tension terminals are not exposed and the current is led into the tube by means of platinum wires attached to carbon electrodes. The electrodes are about eight inches in length. The ends of the tube and the high tension terminals are enclosed in a steel casing so as to effectually prevent anything from coming in contact with the high potential of the system. As stated, the low tension side of the transformer is connected to the usual 60-cycle lighting mains. If direct current is used for distribution, a motor-generator set for furnishing alternating current to the primary of the transformer is required. Any frequency from 60 cycles up is suitable for the operation of these tubes. At lower frequencies there is some appreciable variation of the light emitted. One other device is necessary for the suitable operation of this form of light and this is known as the *regulator*. In order to maintain a constant pressure inside the tube, and such a constant pressure is necessary for its satisfactory operation, there must be some automatic device which will allow a small amount of gas to enter the tube at intervals while it is in operation. The regulator accomplishes this purpose. Fig. 30 shows a diagram of the very simple connections of the system and gives the relative positions occupied by the transformer, tube, and regulator. Fig. 31 gives an enlarged view of the regulator, a description of which and its method of operation is given as follows:

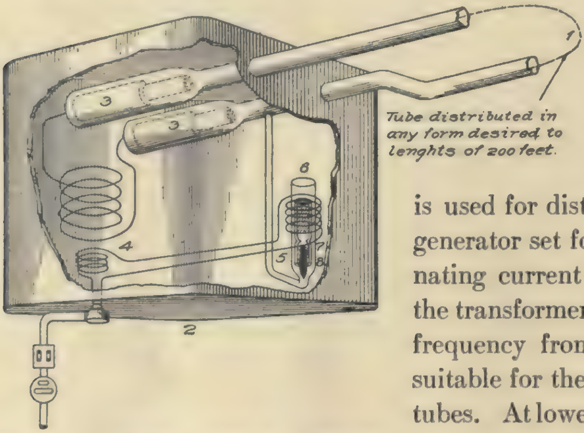

1
3
3
Tube distributed in any form desired to lenghts of 200 feet.
6
4
5
7
8
2

Fig. 30. Diagram Showing Essential Features of the Moore Light. 1. Lighting Tube; 2. Transformer Case; 3. Lamp Terminals; 4. Transformer; 5, 6, 7, 8, Regulators.

A piece of ⅞-inch glass tubing is supported vertically and its bottom end is contracted into a ⅜-inch glass tube which extends to the main lighting tube.

At the point of contraction at the bottom of the ¾-inch tube there is sealed by means of cement a ¼-inch carbon plug, the porosity of which is not great enough to allow mercury to percolate through it but which will permit gases easily to pass, due to the high vacuum of the lighting tube connected to the lower end of the plug, and approximately atmospheric pressure above it. This carbon plug is normally completely covered with what would correspond to a thimbleful of mercury which simply seals the pores of the carbon plug, and therefore has nothing whatever to do with the conducting properties of the gas in the main tube which produces the light. Partly immersed in the mercury and concentric with the carbon plug, is another smaller and movable glass tube, the upper end of which is filled with soft iron wire, which acts as the core of a small solenoid connected in series with the transformer. The action of the solenoid is to lift the concentric glass tube partly out of the mercury, the surface of which falls and thereby causes the minute tip of the conical shaped carbon plug to be slightly exposed for a second or two.

This exposure is sufficient to allow a small amount of gas to enter the tube, the current increases slightly, and the carbon plug is again sealed. The process above described takes place at intervals of about one minute when the tube is in operation.

The color of the light emitted by the tube depends upon the gas used in it. The regulator is fitted with some chemical arrangement whereby the proper gas is admitted to it when the tube is in operation. Nitrogen is employed when the tube gives the highest efficiency and the light emitted when this gas is used is yellowish in color. Air gives a pink appearance to the tube and carbon dioxide is employed when a white light is desired.

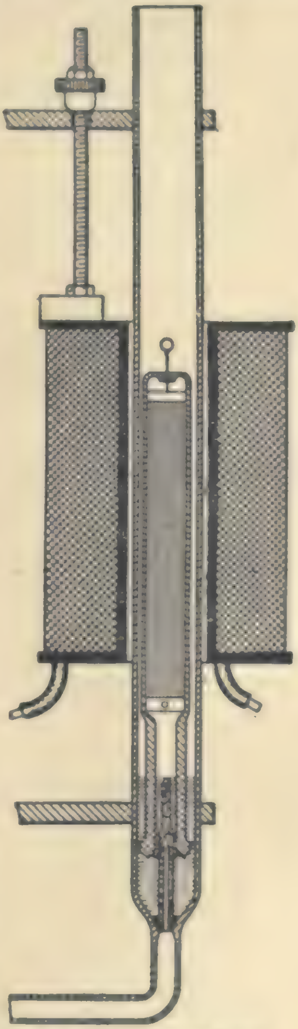


Fig. 31. Regulating Valve.

Table IX gives general data on the Moore tube light. The advantages claimed for this light are: High efficiency, good color, and low intrinsic brilliancy.

TABLE IX

Data on the Moore Tube Light

Length of Tube	Transformer Capacity	Power Factor of Circuit	Voltage at Lamp Terminals
40–70 ft.	2 kw.	65–84%	3,146 for 40-ft. tube, at 12 hefners per ft.
80–125 "	2.75 "		
130–180 "	3.5 "		
190–220 "	4.5 "		12,441 for 220-ft. tube, at 12 hefners per ft.

Pressure in tube, about $\frac{1}{10}$ m.m.
Watts per hefner, 3.2 for 20-foot tube including transformer.
Watts per hefner, 1.4 for 180-foot tube including transformer.
Hefner per foot, normal, 12.
Note that one hefner equals 0.88 candle-power.

ARC LAMPS

The Electric Arc. Suppose two carbon rods are connected in an electric circuit, and the circuit closed by touching the tips of these rods together; on separating the carbons again the circuit will not be broken, provided the space between the carbons be not too great, but will be maintained through the arc formed at these points. This phenomenon, which is the basis of the arc light, was first observed on a large scale by Sir Humphrey Davy, who used a battery of 2,000 cells and produced an arc between charcoal points four inches apart.

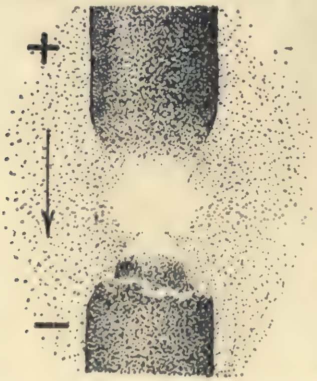


Fig. 32. The Electric Arc between Carbon Terminals.

As the incandescence of the carbons across which an arc is maintained, together with the arc itself, forms the source of light for a large portion of arc lamps, it will be well to study the nature of the arc. Fig. 32 shows the general appearance of an arc between two carbon electrodes when maintained by direct current.

Here the current is assumed as passing from the top carbon to the bottom one as indicated by the arrow and signs. We find, in the direct-current arc, that the most of the light issues from the tip of the positive carbon, or electrode, and this portion is known as the *crater* of the arc. This crater has a temperature of from 3,000° to 3,500° C., the temperature at which the carbon vaporizes, and gives fully 80 to 85% of the light furnished by the arc. The negative carbon becomes pointed at the same time that the positive one is hollowed out to form the crater, and it is also incandescent but not to as great a degree as the positive carbon. Between the electrodes there is a band of violet light, the *arc proper*, and this is surrounded by a luminous zone of a golden yellow color. The arc proper does not furnish more than 5% of the light emitted when pure carbon electrodes are used.

The carbons are worn away or consumed by the passage of the current, the positive carbon being consumed about twice as rapidly as the negative.

The light distribution curve of a *direct-current arc*, taken in a vertical plane, is shown in Fig. 33. Here it is seen that the maximum amount of light is given off at an angle of about 50° from the vertical, the negative carbon shutting off the rays of light that are thrown directly downward from the crater.

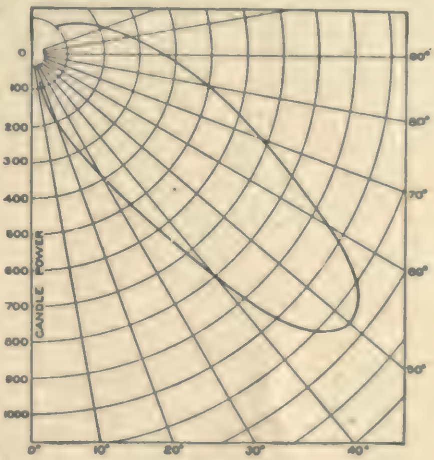


Fig. 33. Distribution Curve for D. C. Arc Lamp (Vertical Plane).

If alternating current is used, the upper carbon becomes positive and negative alternately, and there is no chance for a crater to be formed, both carbons giving off the same amount of light and being consumed at about the same rate. The light distribution curve of an *alternating-current arc* is shown in Fig. 34.

Arc-Lamp Mechanisms. In a practical lamp we must have not only a pair of carbons for producing the arc, but also means for supporting these carbons, together with suitable arrangements for leading the current to them and for maintaining them at the proper distance apart. The carbons are kept separated the proper distance by the operating mechanisms which must perform the following functions:

1. The carbons must be in contact, or be brought into contact, to start the arc when the current first flows.

2. They must be separated at the right distance to form a proper arc immediately afterward.

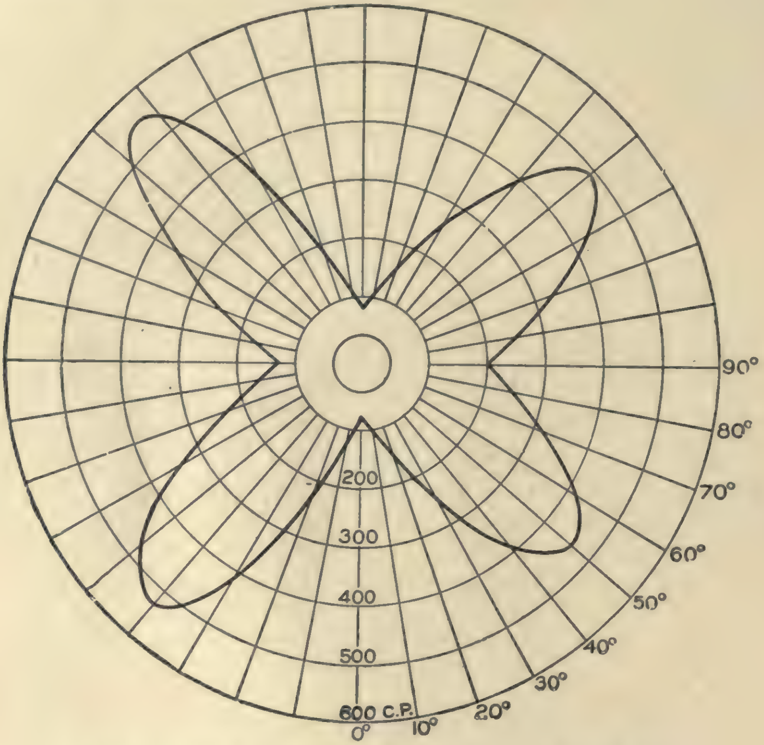
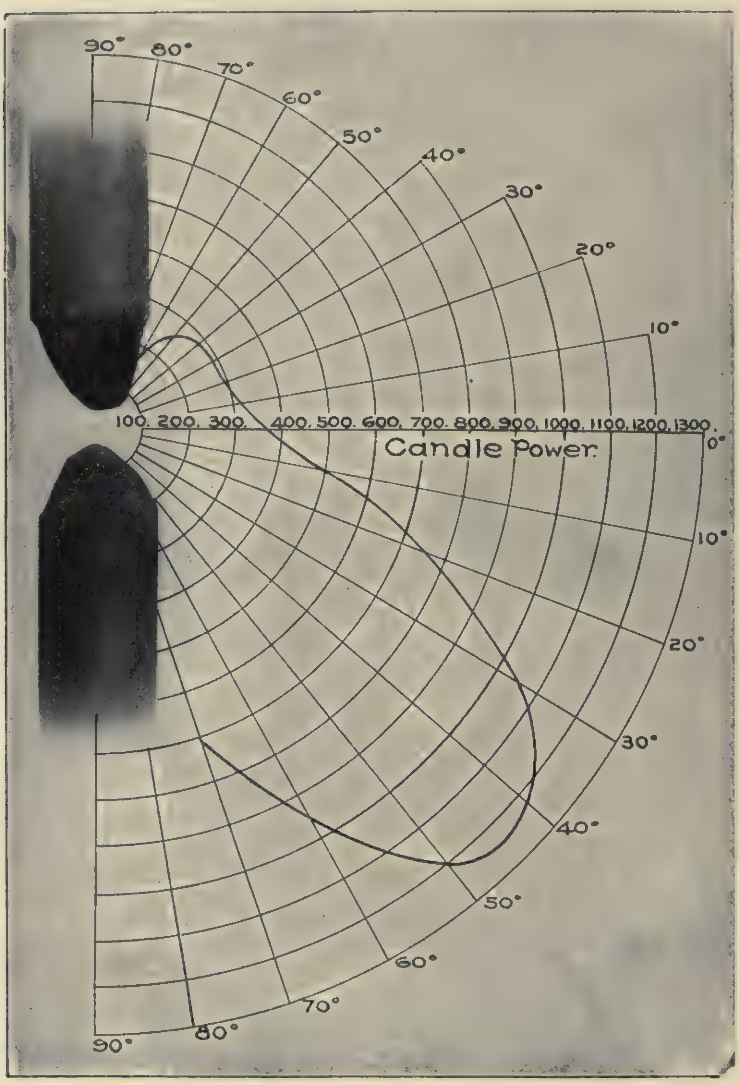


Fig. 34. Distribution Curve for A. C. Arc Lamp (Vertical Plane).

3. The carbons must be fed to the arc as they are consumed.

4. The circuit should be open or closed when the carbons are entirely consumed, depending on the method of power distribution.

The feeding of the carbons may be done by hand, as is the case in some stereopticons using an arc, but for ordinary illumination the striking and maintaining of the arc must be automatic. It is made so in all cases by means of solenoids acting against the force of gravity or against springs. There are an endless number of such mechanisms,



DISTRIBUTION CURVE FOR ARC LAMP.

Fort Wayne Electric Works.

but a few only will be described here. They may be roughly divided into three classes:

1. Shunt mechanisms.
2. Series mechanisms.
3. Differential mechanisms.

Shunt Mechanisms. In shunt lamps, the carbons are held apart before the current is turned on, and the circuit is closed through a solenoid connected in across the gap so formed. All of the current must pass through this coil at first, and the plunger of the solenoid is arranged to draw the carbons together, thus starting the arc. The pull of the solenoid and that of the springs are adjusted to maintain the arc at its proper length.

Such lamps have the disadvantage of a high resistance at the start—450 ohms or more—and are difficult to start on series circuits, due to the high voltage required. They tend to maintain a constant voltage at the arc, but do not aid the dynamo in its regulation, so that the arcs are liable to be a little unsteady.

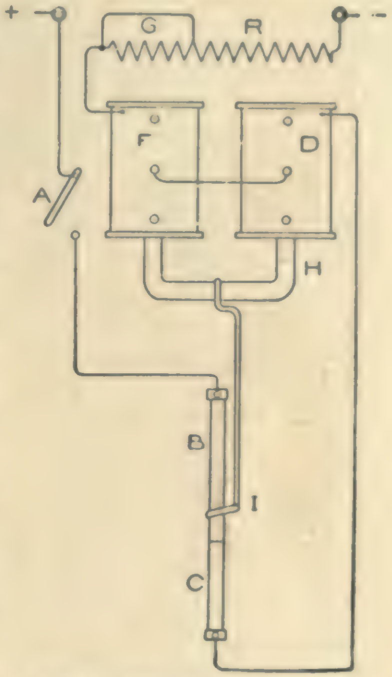


Fig. 35. Series Mechanism for D. C. Arc Lamp.

Series Mechanisms. With the series-lamp mechanism, the carbons are together when the lamp is first started and the current, flowing in the series coil, separates the electrodes, striking the arc. When the arc is too long, the resistance is increased and the current lowered so that the pull of the solenoid is weakened and the carbons feed together. This type of lamp can be used only on constant-potential systems.

Fig. 35 shows a diagram of the connection of such a lamp. This diagram is illustrative of the connection of one of the lamps manufactured by the Western Electric Company, for use on a direct-current, constant-potential system. The symbols + and − refer to the terminals of the lamp, and the lamp must be so connected that the current flows from the top carbon to the bottom one. R is a series resistance, adjustable for different voltages by means of the shunt G. F and D are the controlling solenoids connected in series with the arc. B and C are the positive and negative carbons respectively, while A is the switch for turning the current on and off. H is the plunger of the solenoids and I the carbon clutch, this being what is known as a *carbon-feed lamp.* The carbons are together when A is first closed, the current is excessive, and the plunger is drawn up into the solenoids, lifting the carbon B until the resistance of the arc lowers the current to such a value that the pull of the solenoid just counterbalances the weight of the plunger and carbon. G must be so adjusted that this point is reached when the arc is at its normal length.

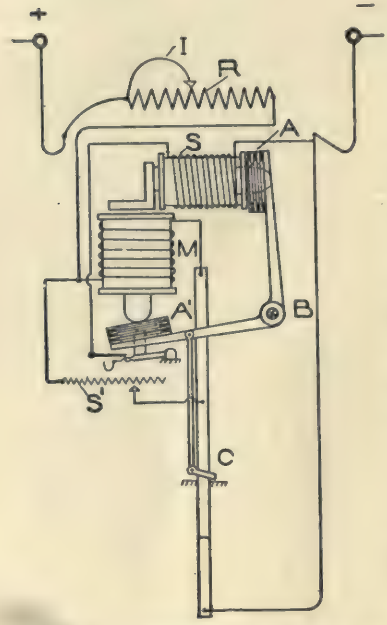


Fig. 36. Differential Mechanism for D. C. Arc Lamp.

Differential Mechanisms. In the differential lamp, the series and shunt mechanisms are combined, the carbons being together at the start, and the series coil arranged so as to separate them while the shunt coil is connected across the arc, as before, to prevent the carbons from being drawn too far apart. This lamp operates only over a low-current range, but it tends to aid the generator in its regulation.

Fig. 36 shows a lamp having a differential control, this also being the diagram of a Western Electric Company arc lamp for a direct-current, constant-potential system. Here S represents the shunt coil and M the series coil, the armature of the two magnets A and A' being attached to a bell-crank, pivoted at B, and attached to the carbon clutch C. The pull of coil S tends to lower the carbon while that of M raises the carbon, and the two are so adjusted that equilibrium is reached when the arc is of the proper length. All of the lamps are fitted with an air dashpot, or some damping device, to prevent too rapid movements of the working parts.

The methods of supporting the carbons and feeding them to the arc may be divided into two classes:

1. Rod-feed mechanism.
2. Carbon-feed mechanism.

Rod-Feed Mechanism. Lamps using a rod feed have the upper carbons supported by a conducting rod, and the regulating mechanism acts on this rod, the current being fed to the rod by means of a sliding contact. Fig. 37 shows the arrangement of this type of feed. The rod is shown at *R*, the sliding contact at *B*, and the carbon is attached to the rod at *C*.

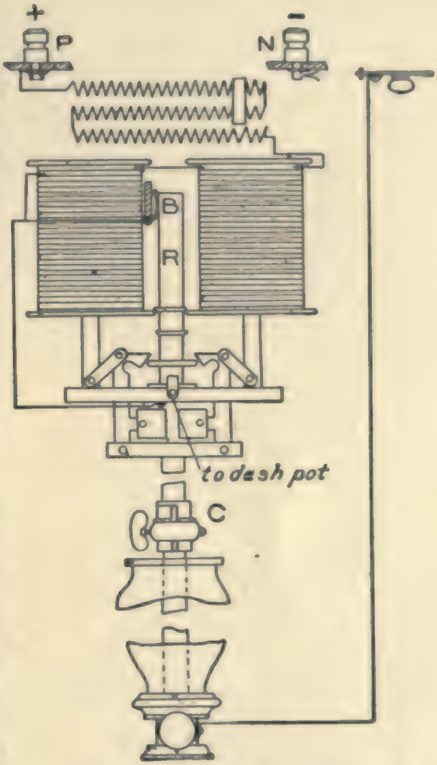


Fig. 37. Rod-Feed Mechanism.

These lamps have the advantage that carbons, which do not have a uniform cross-section or smooth exterior, may be used, but they possess the disadvantage of being very long in order to accommodate the rod. The rod must also be kept clean so as to make a good contact with the brush.

Carbon-Feed Mechanism. In carbon-feed lamps the controlling mechanism acts on the carbons directly through some form of clutch such as is shown at *C* in Fig. 38. This clamp grips the carbon when it is lifted, but allows the carbon to slip through it when the tension is released. For this type of feed the carbon must be straight and have a uniform cross-section as well as a smooth exterior. The current may be led to the carbon by means of a flexible lead and a short carbon holder.

TYPES OF ARC LAMPS

Arc lamps are constructed to operate on *direct-current* or *alternating-current* systems when connected in *series* or in *multiple*. They are also made in both the *open* and the *enclosed* forms.

By an *open arc* is meant an arc lamp in which the arc is exposed to the atmosphere, while in the *enclosed arc* an inner or enclosing globe surrounds the arc, and this globe is covered with a cap which renders it nearly air-tight. Fig. 38 is a good example of an enclosed arc as manufactured by the General Electric Company.

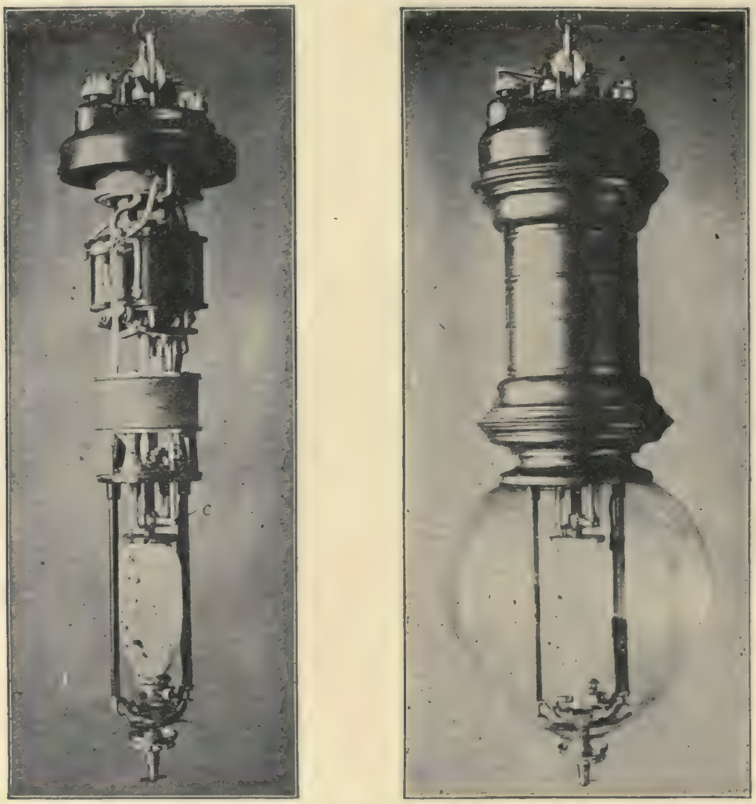


Fig. 38. Enclosed Arc Lamp with Carbon-Feed Mechanism.

Direct-Current Arcs. *Open Types of Arcs* for direct-current systems were the first to be used to any great extent. When used they are always connected in series, and are run from some form of special arc machine, a description of which may be found in "Types of Dynamo Electric Machinery."

Each lamp requires in the neighborhood of 50 volts for its operation, and, since the lamps are connected in series, the voltage of the system will depend on the number of lamps; therefore, the number of lamps that may be connected to one machine is limited by the maximum allowable voltage on that machine. By special construction as many as 125 lamps are run from one machine, but even this size of generator is not so efficient as one of greater capacity. Such generators are usually wound for 6.6 or 9.6 amperes. Since the carbons are exposed to the air at the arc, they are rapidly consumed, requiring that they be renewed daily for this type of lamp.

Double-carbon arcs. In order to increase the life of the early form of arc lamp without using too long a carbon, the double-carbon type was introduced. This type uses two sets of carbons, both sets being fed by one mechanism so arranged that when one pair of the electrodes is consumed the other is put into service. At present nearly all forms of the open arc lamp have disappeared on account of the better service rendered by the enclosed arc.

Enclosed arcs for series systems are constructed much the same as the open lamp, and are controlled by either shunt or differential mechanism. They require a voltage from 68 to 75 at the arc, and are usually constructed for from 5 to 6.8 amperes. They also require a constant-current generator or a rectifier outfit if used on alternating-current circuits.

Constant-potential arcs must have some resistance connected in series with them to keep the voltage at the arc at its proper value. This resistance is made adjustable so that the lamps may be used on any circuit. Its location is clearly shown in Fig. 38, one coil being located above, the other below the operating solenoids.

Alternating-Current Arcs. These do not differ greatly in construction from the direct-current arcs. When iron or other metal parts are used in the controlling mechanism, they must be laminated or so constructed as to keep down induced or eddy currents which might be set up in them. For this reason the metal spools, on which the solenoids are wound, are slotted at some point to prevent them from forming a closed secondary to the primary formed by the solenoid winding. On constant-potential circuits a reactive coil is used in place of a part of the resistance for cutting down the voltage at the arc.

Interchangeable Arc. Interchangeable arcs are manufactured which may be readily adjusted so as to operate on either direct or alternating current, and on voltages from 110 to 220. Two lamps may be run in series on 220-volt circuits.

The distribution of light, and the resulting illumination for the different lamps just considered, will be taken up later. Aside from the distribution and quality of light, the enclosed arc has the advantage that the carbons are not consumed so rapidly as in the open lamp because the oxygen is soon exhausted from the inner globe and the combustion of the carbon is greatly decreased. They will burn from 80 to 100 hours without retrimming.

TABLE X

Rating of Enclosed Arcs

		Watts Consumed					Mean Intensity in H. U.			Mean Watts		
D. C. Lamp	Current	In Lamp		In Arc		Mechanism	Spherical		Lower Hemi-spherical	Spherical H. U.		Lower Hemi-spherical
							Opal Outer	Clear Outer	Clear Outer	Opal Outer	Clear Outer	Clear Outer
								235	332		2.37	1.66
1	5.01	551		401		150	172	256*	362*	3.10	2.18*	1.52*
3	5.08	559		406		252	195	216	282	2.85	2.60	1.99
4	4.76	524		381		143	127	139	208	4.12	3.76	2.52
5	4.16†	458		333		125	154	174	221	2.96	2.63	2.07
7	4.76	524		381		143	203	333	317	2.63	2.20	1.65
9	4.84	532		387		145	182	226	281	2.83	2.38	1.89
10	4.99	549		399		150	202	242	309	2.74	2.24	1.77
12	4.87	536		390		146	178	195	230	3.05	2.66	2.33
Mean	4.9	529		384		144	176	207	272	3.03	2.60	1.98
A. C. Lamp	Current	In Lamp	Power Factor Lamp	In Arc	Power Factor Arc	Mechanism						
101	6.40	448	.63	340	.82	108	127	141	206	3.52	3.17	2.17
								203	236		2.26	1.94
102	6.79	459	.61	375	.73	84	146	176†	226†	3.31	2.60†	1.72†
103	5.89	424	.65	344	.75	80	116	130	147	3.66	3.15	2.88
105	6.20	414	.61	382	.80	32	128	187	219	3.24	2.20	1.89
								153	169		2.56	2.23
106	6.12	378	.56	298	.70	80	132	182†	284	2.82	2.19†	1.48†
108	6.48	457	.64	383	.80	74.5	133	175	211	3.20	2.61	2.16
110	6.18	339	.49	276	.72	63	140*	126	143	2.41*	2.68	2.37
Mean	6.29	417	.60	342	.76	74.5	130	159	190	3.31	2.66	2.23

*Condition of no outer globe. †Condition with shade on lamp. H.U. Hefner Units.

Rating of Arc Lamps. Open arcs have been classified as follows:

Full Arcs, 2,000 candle-power taking 9.5 to 10 amps. or 450-480 watts.
Half Arcs, 1,200 candle-power taking 6.5 to 7 amps. or 325-350 watts.

These candle-power ratings are much too high, and run more nearly 1,200 and 700, respectively, for the point of maximum intensity and less than this if the mean spherical candle-power be taken. For this reason, the ampere or watt rating is now used to indicate the power of the lamp. It is now recommended that specifications for street lighting should be based upon the illumination produced. This point is considered later under the topic of street lighting. Enclosed arcs use from 3 to 6.5 amperes, but the voltage at the arc is higher than for the open lamp. Table X gives some data on enclosed arcs on constant-potential circuits.

Efficiency. The efficiency of arc lamps is given as follows:

Direct-Current Arc (enclosed) 2.9 watts per candle-power.
Alternating-Current Arc (enclosed) 2.95 watts per candle-power.
Direct-Current Arc (open) .6–1.25 watts per candle-power.

Carbons for Arc Lamps. Carbons are either moulded or forced from a product known as *petroleum coke* or from similar materials such as *lampblack*. The material is thoroughly dried by heating to a high temperature, then ground to a find powder, and combined with some substance such as pitch which binds the fine particles of carbon together. After this mixture is again ground it is ready for moulding. The powder is put in steel moulds and heated until it takes the form of a paste, when the necessary pressure is applied to the moulds. For the forced carbons, the powder is formed into cylinders which are placed in machines which force the material through a die so arranged as to give the desired diameter. The forced carbons are often made with a core of some special material, this core being added after the carbon proper has been finished. The carbons, whether moulded or forced, must be carefully baked to drive off all volatile matter. The forced carbon is always more uniform in quality and cross-section, and is the type of carbon which must be used in the carbon-feed lamp. The adding of a core of a different material seems to change the quality of light, and being more readily volatilized, keeps the arc from wandering.

Plating of carbons with copper is sometimes resorted to for moulded forms for the purpose of increasing the conductivity, and, by protecting the carbon near the arc, prolonging the life.

The Flaming Arc. In the carbon arc the arc proper gives out but a small percentage of the total amount of light emitted. In order to obtain a light in which more of the source of luminosity is in the arc itself, experiments have been made with the use of electrodes impregnated with certain salts, as well as with electrodes of a material different than carbon. The result of these experiments has been to place upon the market the flaming arc lamps and the luminous arc lamps—lamps of high candle-power, good efficiency, and giving various colors of light. These lamps may be put in two classes: One class uses carbon electrodes, these electrodes being impregnated with certain salts which add luminosity to the arc, or else fitted with cores which contain the required material; the other class covering lamps which do not employ carbon, the most notable example being the magnetite arc which uses a copper segment as one electrode and a magnetite stick as the other electrode.

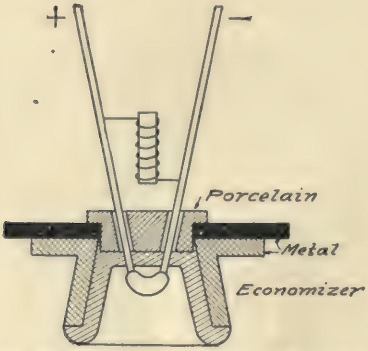


Fig. 39. Diagram of Bremer Flaming Arc.

Flaming arcs of the first class are made in two general types: One in which the electrodes are placed at an angle, and the other in which the carbons are placed one above the other as in the ordinary arc lamp. The term luminous arc is usually applied to arcs of the flaming type in which the electrodes are placed one above the other. The minor modifications as introduced by the various manufacturers are numerous and include such features as a magazine supply of electrodes by which a new pair may be automatically introduced when one pair is consumed; feed and control mechanisms; etc. The flaming arc presents a special problem since the vapors given off by the lamp may condense on the glassware and form a partially opaque coating, or they may interfere with the control mechanism.

Bremer Arc. The Bremer flaming arc lamp was introduced commercially in 1899, and since some of its principles are incorporated in many of the lamps on the market to-day, it will be briefly described here. The diagram shown in Fig. 39 illustrates the main features of this lamp. The electrodes are mounted at an angle and an electromagnet is placed above the arc for the purpose of keeping the arc from creeping up and injuring the economizer, and also for the purpose of spreading the arc out and increasing its surface. The vapor from the arc is condensed on the economizer and this coating acts as a reflector, throwing the light downward. The economizer serves to limit the air supplied to the arc and thus increases the life of the electrodes. The inclined position of the carbons was suggested by the fact that in the impregnated carbons a slag was formed which gave trouble when the electrodes were mounted in the usual manner. By using the electrodes in this position there is little if any obstruction to the light which passes directly downward from the arc.

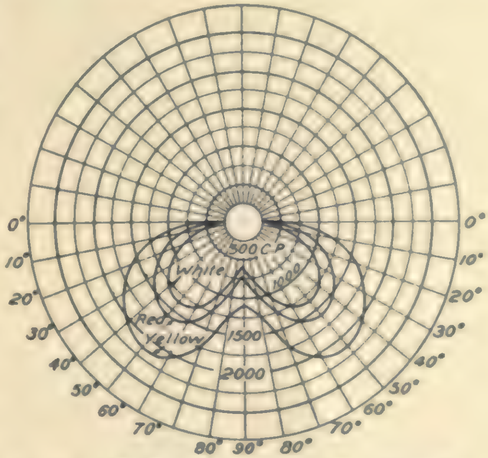


Fig. 40. Distribution Curves of a Luminous Arc.

Bremer's original electrodes contained compounds of calcium, strontium, magnesium, etc., as well as boracic acid. Electrodes as employed in the various lamps to-day differ greatly in their make-up. Some use impregnated carbons, others use carbons with a core containing the flaming materials, and metallic wires are added in some cases. The life of electrodes for flaming lamps is not great, depending upon their length and somewhat upon the type of lamp. The maximum life of the treated carbons is in the neighborhood of 20 hours.

The color of the light from the flaming arc is yellow when calcium salts are used as the main impregnating compound, and the majority of the lamps installed use electrodes giving a yellow light. By employing more strontium, a red or pink light is produced, while if a white light is wanted, barium salts are used. Calcium gives the most efficient service and strontium comes between this and barium. The distribution curves in Fig. 40 illustrate the relative economies of the different materials. Modern electrodes contain not more than 15% of added material and it is customary to find the salts applied as a core to the pure carbon sticks. The electrodes are made of a small diameter in order to maintain a steady light and this partially accounts for their short life.

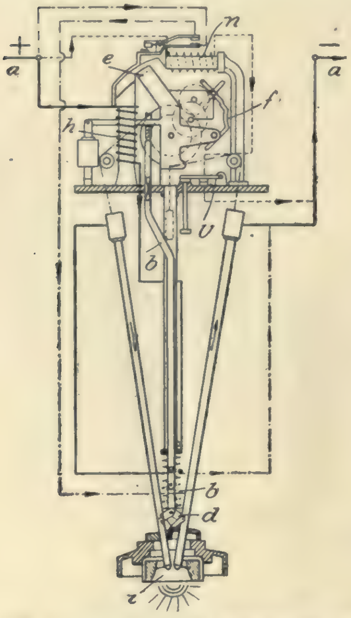


Fig. 41. Clock Feeding Mechanism for Luminous Arc Lamp.

The feeding mechanisms employed differ greatly. They may be classified as: Clock, gravity-feed, clutch, motor, and hot-wire mechanisms. Fig. 41 illustrates a clock mechanism. This is a differential mechanism in which the shunt coils act to release a detent *f* which allows the electrodes to feed down and when they come in contact the series coils separate them to the proper extent for maintaining a suitable arc. In the gravity feed an electromagnet is used to operate one carbon in springing the arc and the other carbon is fed by gravity, it being prevented from dropping too far by means of a special rib formed on the electrode which comes in contact with a part of the lamp structure. Gravity feed is also employed in the clutch mechanism but here the carbons are held in one position by an electrically operated clutch which releases them only when the current is sufficiently reduced by the lengthening of the arc. In the hot-wire lamp, the wire is usually in series with the arc; the contraction and expansion of this wire is balanced against a spring and the arc is regulated by such contraction or expansion of the wire. Such a lamp is suitable for either direct or alternating current. In the motor mechanism, as applied to alternating-current lamps, a metallic disk is actuated by differential magnets and its motion is transmitted to the electrodes to lengthen or shorten the arc accordingly as the force exerted by the series or shunt coils predominates.

Magnetite Arc. The magnetite arc employs a copper disk as one electrode; and a magnetite stick—formed by forcing magnetite, to which titanium salts are usually added, into a thin sheet steel tube—is used as the other electrode. This lamp gives a luminous arc of good efficiency and the magnetite electrode is not consumed as rapidly as the treated carbons with the result that magnetite lamps do not require trimming as frequently. The life of the magnetite electrode as at present manufactured is from 170 to 200 hours. A diagram of the connections of this lamp as manufactured by the General Electric Company is shown in Fig. 42. The magnetite electrode is placed below. The copper electrode has just the proper dimensions to prevent its being destroyed by the arc and yet it is not large enough to cause undue condensation of the arc vapor. Direct current must be used with this lamp, the current passing from the copper to the magnetite.

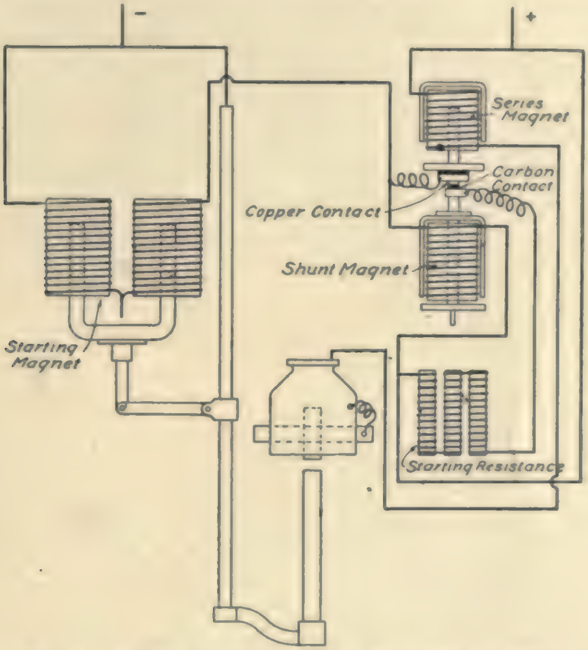


Fig. 42. Diagram of Connections for Magnetite Arc Lamp.

Table XI gives some general data on the flaming arc, while Figs. 43 and 44 give typical distribution curves. The advantages of the flaming arc over lamps using pure carbon electrodes are: High efficiency; better light distribution; and better color of light for some purposes. A greater amount of light can be obtained from a single unit than is practical with the carbon arc. The disadvantages lie in the frequent trimming required and the expense of electrodes. Flaming arcs have been introduced abroad, especially in Germany, to a much greater extent than in the United States.

TABLE XI

General Data on Flaming Arcs

Volts	Amperes	Watts	Mean Spherical Candle-Power	Watts per Mean Spherical C. P.
55	6	330	480	.68
	8	440	800	.55
	10	550	1100	.5
	12	660	1300	.5
	15	825	1700	.49
	20	1100	2250	.48

POWER DISTRIBUTION

The question of power distribution for electric lamps and other appliances is taken up fully in the section on that subject, therefore it will be treated very briefly here. The systems may be divided into:

1. Series distribution systems.
2. Multiple-series or series-multiple systems.
3. Multiple or parallel systems.

They apply to both alternating and direct current.

The Series System. This is the most simple of the three; the lamps, as the name indicates, are connected in series as shown in Fig. 45. A constant load is necessary if a constant potential is to be used. If the load is variable, a constant-current generator, or a special regulating device is necessary. Such devices are constant-current transformers and constant-current regulators as applied to alternating-current circuits.

The series system is used mostly for arc and incandescent lamps when applied to street illumination. Its advantages are simplicity and saving of copper. Its disadvantages are high voltage, fixed by the number of lamps in series; the size of the machines is limited since they cannot be insulated for voltage above about 6,000; a single open circuit shuts down the whole system.

Alternating-current series distribution systems are being used to a very large extent. By the aid of special transformers, or regulators, any number of circuits can be run from one machine or set of bus bars, and apparatus can be built for any voltage and of any size. It is not customary, however, to build transformers of this type having a capacity greater than one hundred 6.6-ampere lamps because of the high voltage which would have to be induced in the secondary for a larger number of lamps.

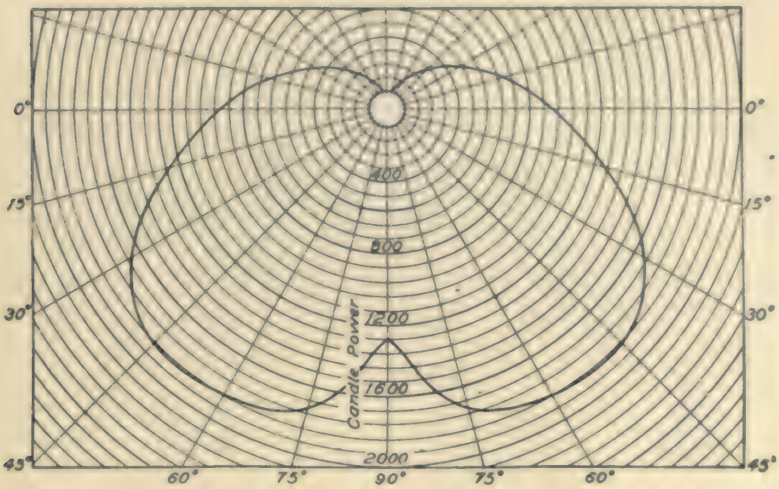


Fig. 43. Distribution Curve for Flaming Arc Lamp.

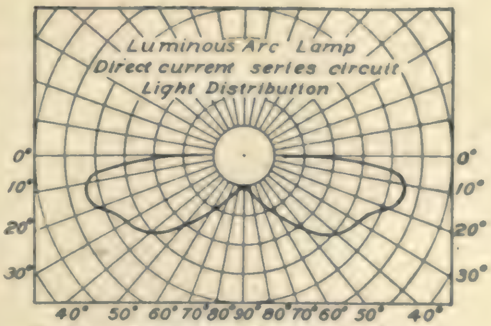


Fig. 44. Distribution Curve for a 4-Ampere, 75-Volt, Magnetite Luminous Arc Lamp.

Fig. 45 gives a diagram of the connection of a single-coil transformer in service. The constant-current transformer most in use for lighting purposes is the one manufactured by the General Electric Company and commonly known as a *tub transformer*. Fig. 46 shows such a transformer (double-coil type) when removed from the case.

Referring to Fig. 46, the fixed coils *A* form the primaries which are connected across the line; the movable coils *B* are the secondaries connected to the lamps. There is a repulsion of the coils *B* by the coils *A* when the current flows in both circuits and this force is balanced by means of the weights at *W*, so that the coils *B* take a position such that the normal current will flow in the secondary. On light loads, a low voltage is sufficient, hence the secondary coils are close together near the middle of the machine and there is a heavy magnetic leakage. When all of the lamps are on, the coils take the position shown when the leakage is a minimum and the voltage a maximum. When first starting up, the transformer is short-circuited and the secondary coils brought close together. The short circuit is then removed and the coils take a position corresponding to the load on the line.

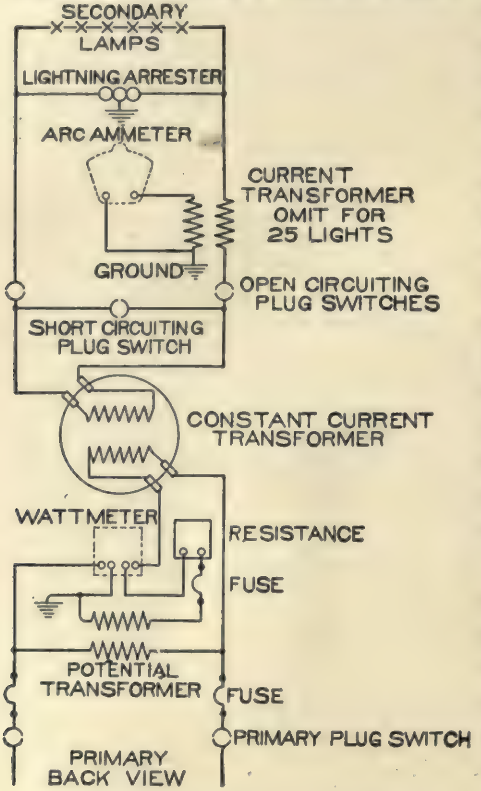


Fig. 45. Wiring Diagram for Single-Coil Transformer.

These transformers regulate from full load to $\frac{1}{3}$ rated load within $\frac{1}{10}$ ampere of normal current, and can be run on short circuit for several hours without overheating. The efficiency is given as 96% for 100-light transformers and 94.6% for 50-light transformers at full load. The power factor of the system is from 76 to 78% on full load, and, owing to the great amount of magnetic leakage at less than full load—the effect of leakage being the same as the effect of an inductance in the primary—the power factor is greatly reduced, falling to 62% at $\frac{3}{4}$ load, 44% at $\frac{1}{2}$ load, and 24% at $\frac{1}{4}$ load.

Standard sizes are for capacities of 25-, 35-, 50-, 75-, and 100-6.6 ampere enclosed arcs, and they are also made for lower currents in

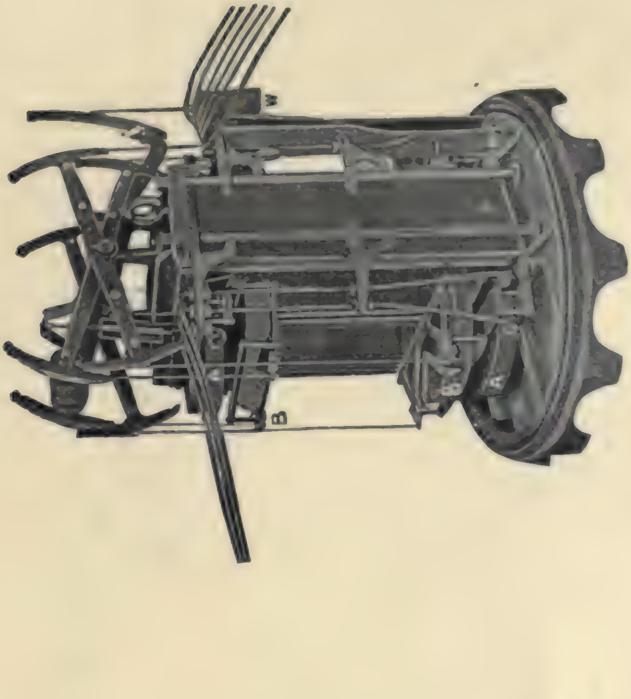


Fig 46. Double-Coil Transformer (second view with case removed).

the neighborhood of 3.3 amperes for incandescent lamps. The low power factor of such a system on light loads shows that a transformer should be selected of such a capacity that it will be fully or nearly fully loaded at all times. The primary winding can be constructed for any voltage and the open circuit voltages of the secondaries are as follows:

25 light	transformer,	2,300 volts.	75 light	transformer,	6,900 volts.
35 "	"	3,200 "	100 "	"	9,200 "
50 "	"	4,600 "			

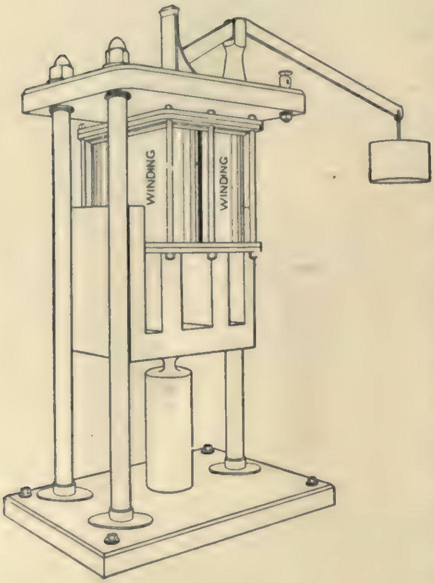
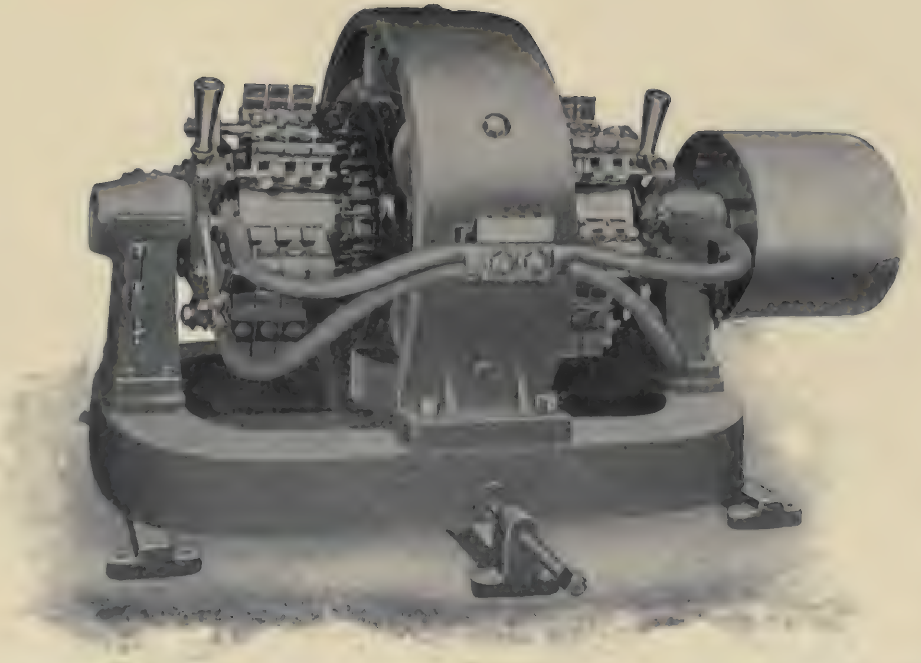


Fig. 47. Current Regulator for A. C. Series Distribution Systems.

The 50-, 75-, and 100-light transformers are arranged for multiple circuit operation, two circuits used in series, and the voltages at full load reach 4,100 for each circuit on the 100-light machine.

The second system, used for series distribution on alternating-current circuits consists of a constant-potential transformer, stepping down the line voltage to that required for the total number of lamps on the system, allowing 83 volts for each lamp, and in series with the lamps is a reactive coil, the reactance of which is automatically regulated, as the load is increased or decreased, in order to keep the current in the line constant. Fig. 47 shows such a regulator and Fig. 48 shows this regulator connected in circuit. The inductance is varied by the movement of the coil so as to include more or less iron in the magnetic circuit. Since the inductance in series with the lamps is high on light loads, the power factor is greatly reduced as in the constant-current transformer; and the circuits should, preferably, be run fully loaded. 60 to 65 lamps on a circuit is the usual maximum limit.

While used primarily for arc-light circuits, the same systems,



SPECIAL LOW VOLTAGE GENERATOR WITH LARGE CURRENT CAPACITY FOR ELECTROLYTIC WORK

designed for lower currents, are very readily applied to series incandescent systems.

The introduction of certain flaming or luminous arcs requiring direct current for their operation has led to the use of the *mercury arc rectifier* in connection with series circuits on alternating-current systems. A constant-current transformer is used to regulate for the proper constant current in its secondary winding, and this secondary current is rectified by means of the mercury arc rectifier for the lamp circuit. In the recent outfits the rectifier tubes are immersed in oil for cooling. While this rectifier was first introduced for the operation of luminous arc lamps, there is no reason why it should not be used with any series lamp requiring direct current, provided the system is designed for the current taken by such lamps. With this system any commercial frequency may be used. Sets are constructed for 25-, 50-, and 75-light circuits. They have a combined efficiency, transformer and rectifier tube, of 85% to 90%, and operate at a power factor of from 65% to 70%. Fig. 49 gives a diagram of the circuit and rectifier connections used with a single-tube outfit.

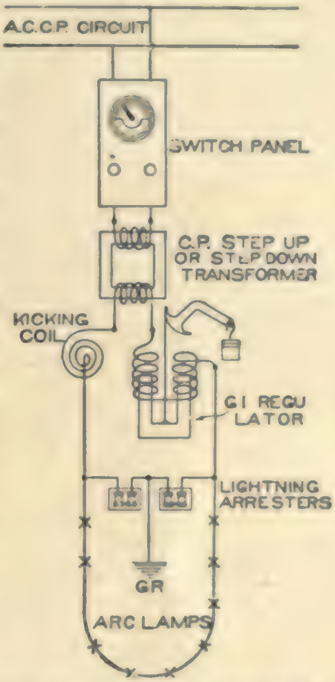


Fig. 48. Wiring Diagram Showing Introduction of the Current Regulator.

Multiple-Series or Series-Multiple Systems. These combine several lamps in series, and these series groups in multiple, or several lamps in multiple and these multiple groups in series, respectively. They have but a limited application.

Multiple or Parallel Systems of Distribution. By far the largest number of lamps in service are connected to parallel systems of distribution. In this system, the units are connected across the lines leading to the bus bars at the station, or to the secondaries of constant-potential transformers. Fig. 50 shows a diagram of ten lamps connected in parallel. The current delivered by the machine depends directly on the number of lamps connected in service, the voltage of the system being kept constant.

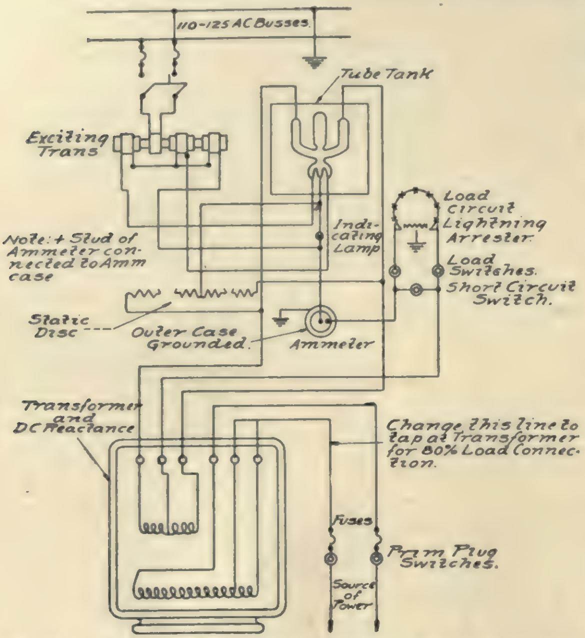

110-125 AC Busses.
Tube Tank
Exciting Trans
Load Circuit Lightning Arrester.
Indicating Lamp
Note: + Stud of Ammeter connected to Amm case
Load Switches.
Short Circuit Switch.
Static Disc
Outer Case Grounded.
Ammeter
Transformer and DC Reactance
Change this line to tap at Transformer for 80% Load Connection.
Fuses
Prim Plug Switches.
Source of Power

Fig. 49. Wiring Diagram for A. C. System Showing Introduction of Mercury Arc Rectifier.

Inasmuch as the flow of current in a conductor is always accompanied by a fall of potential equal to the product of the current flowing into the resistance of the conductor, the lamps at the end of the system shown will not have as high a voltage impressed upon them as those nearer the machine. This drop in potential is the most serious obstacle that we have to overcome in multiple systems, and various schemes have been adopted to aid in this regulation. The systems may be classified as:

1. Cylindrical conductors, parallel feeding.
2. Conical " " "
3. Cylindrical " anti-parallel feeding.
4. Conical " " "

In the cylindrical conductor, parallel-feeding system, the conductors, *A*, *B*, *C*, *D*, Fig. 50, are of the same size throughout and are fed at the same end by the generator. The voltage is a minimum at the lamps *E* and a maximum at the lamps *F;* the value of the voltage at any lamp being readily calculated.

By a *conical* or *tapering conductor* is meant a conductor whose diameter is so proportioned throughout its length that the current, divided by the cross-section, or the current density, is a constant quantity. Such a conductor is approximated in practice by using smaller sizes of wire as the current in the lines becomes less.

In an anti-parallel system, the current is fed to the lamps from opposite ends of the system, as shown in Fig. 51.

Multiple-Wire Systems. In order to take advantage of a higher voltage for distribution of power to the lighting circuits, three- and five-wire systems have been introduced, the three-wire system being used to a very large extent. In this system, three conductors are used, the voltage from each outside conductor to the middle neutral conductor being the same as for a simple parallel system. Fig. 52 gives a diagram of this. By this system the amount of copper required for a given number of lamps is from five-sixteenths to three-eighths of the amount required for a two-wire distribution, depending on the size of the neutral conductor. The saving of copper together with the disadvantages of the system is more fully treated in the paper on "Power Transmission."

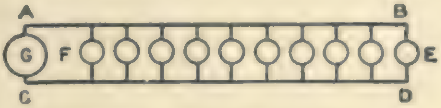


Fig. 50. Parallel Feeding System.

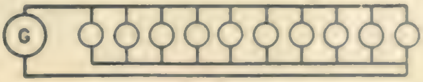


Fig. 51. Anti-parallel Feeding System.

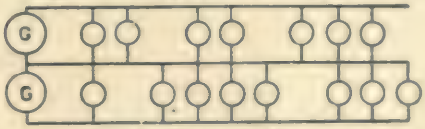


Fig. 52 Three-wire System.

ILLUMINATION

Illumination may be defined as the quality and quantity of light which aids in the discrimination of outline and the perception of color. Not only the quantity, but the quality of the light, as well as the arrangement of the units, must be considered in a complete study of the subject of illumination.

Unit of Illumination. The unit of illumination is the *foot-candle* and its value is the amount of light falling on a surface at a distance of one foot from a source of light one candle-power in value. The law of inverse squares—namely, that the illumination from a given source varies inversely as the square of the distance from the source—shows that the illumination at a distance of two feet from a single candle-power unit is .25 foot-candles. For further consideration of the law of inverse squares, see "Photometry."

Illumination may be classified as *useful*—when used for the ordinary purposes of furnishing light for carrying on work, taking the place of daylight; and *scenic*—when used for decorative lighting such as stage lighting, etc. The two divisions are not, as a rule, distinct, but the one is combined with the other.

Intrinsic Brightness. By intrinsic brightness is meant the amount of light emitted per unit surface of the light source. Table XII gives the intrinsic brightness of several light sources.

TABLE XII

Intrinsic Brilliancies in Candle-Power per Square Inch

SOURCE	BRILLIANCY	NOTES
Sun in zenith	600,000	Rough equivalent values, taking account of absorption
Sun at 30 degrees elv.	500,000	
Sun on horizon	2,000	
Arc light	10,000 to 100,000	Maximum about 200,000 in crater
Calcium light	5,000	
Nernst "glower"	1,000	Unshaded
Incandescent lamp	200–300	Depending on efficiency
Enclosed arc	75–100	Opalescent inner globe
Acetylene flame	75–100	
Welsbach light	20 to 25	
Kerosene light	4 to 8	Variable
Candle	3 to 4	
Gas flame	3 to 8	Variable
Incandescent (frosted)	2 to 5	
Opal shaded lamps, etc.	0.5 to 2	

Regular Reflection. Regular reflection is the term applied to reflection of light when the reflected rays are parallel. It is of such a nature that the image of the light source is seen in the reflection. The reflection from a plane mirror is an example of this. It is useful in lighting in that the direction of light may be changed without complicating calculations aside from deductions necessary to compensate for the small amount of light absorbed.

Irregular Reflection. Irregular reflection, or diffusion, consists of reflection in which the reflected rays of light are not parallel but take various directions, thus destroying the image of the light source. Rough, unpolished surfaces give such reflection. Smooth, unpolished surfaces generally give a combination of two kinds of reflection.

Diffused reflection is very important in the study of illumination inasmuch as diffused light plays an important part in the lighting of interiors. This form of reflection is seen in many photometer screens. Light is also diffused when passing through semi-transparent shades or screens.

In considering reflected light, we find that, if the surface on which the light falls is colored, the reflected light may be changed in its nature by the absorption of some of the colors. Since, as has been said, in interior lighting the reflected light forms a large part of the source of illumination, this illumination will depend upon the nature and the color of the reflecting surfaces.

Whenever light is reflected from a surface, either by direct or diffused reflection, a certain amount of light is absorbed by the surface. Table XIII gives the amount of white light reflected from different materials.

TABLE XIII

Relative Reflecting Power

Material	%
White blotting paper	82
White cartridge paper	80
Chrome yellow paper	62
Orange paper	50
Yellow wall paper	40
Light pink paper	36
Yellow cardboard	30
Light blue cardboard	25
Emerald green paper	18
Dark brown paper	13
Vermilion paper	12
Blue-green paper	12
Black paper	5
Black cloth	1.2
Black velvet	.4

From this table it is seen that the light-colored papers reflect the light well, but of the darker colors only yellow has a comparatively high coefficient of reflection. Black velvet has the lowest value, but this only holds when the material is free from dust. Rooms with dark walls require a greater amount of illuminating power, as will be seen later.

Useful illumination may be considered under the following heads:

1. Residence Lighting.
2. Lighting of Public Halls, Offices, Drafting Rooms, Shops, etc.
3. Street Lighting.

RESIDENCE LIGHTING

Type of Lamps. The lamps used for this class of lighting are limited to the less powerful units—namely, incandescent or Nernst lamps varying in candle-power from 8 to 50 per unit. These should always be shaded so as to keep the intrinsic brightness low. The intrinsic brilliancy should seldom exceed 2 to 3 candle-power per square inch, and its reduction is usually accomplished by appropriate shading. Arc lights are so powerful as to be uneconomical for small rooms, while the color of the mercury-vapor light is an additional objection to its use.

Plan of Illumination. Lamps may be selected and so located as to give a brilliant and fairly uniform illumination in a room; but this is an uneconomical scheme, and the one more commonly employed is to furnish a uniform, though comparatively weak, ground illumination, and to reinforce this at points where it is necessary or desirable. The latter plan is satisfactory in almost all cases and the more economical of the two.

While the use of units of different power is to be recommended, where desirable, lights differing in color should not be used for lighting the same room. As an exaggerated case, the use of arc with incandescent lamps might be mentioned. The arcs being so much whiter than the incandescent lamps, the latter appear distinctly yellow when the two are viewed at the same time.

Calculation of Illumination. In determining the value of illumination, not only the candle-power of the units, but the amount of reflected light must be considered for the given location of the lamps. Following is a formula based on the coefficient of reflection of the walls of the room, which serves for preliminary calculations:

$$I = \frac{c.p. \quad \frac{1}{1-k}}{d^2}$$

I = Illumination in foot-candles.
$c.p.$ = Candle-power of the unit.
k = Coefficient of reflection of the walls.
d = distance from the unit in feet.

Where several units of the same candle-power are used this formula becomes:

$$I = c.p. \left(\frac{1}{d^2} + \frac{1}{d^2_1} + \frac{1}{d^2_2} + ----------\right)\frac{1}{1-k}$$

or,
$$c.p. = \frac{1}{\left(\frac{1}{d^2} + \frac{1}{d^2_1} + \frac{1}{d^2_2} + ----------\right)\frac{1}{1-k}}$$

where d, d_1, d_2, etc., equal the distances from the point considered to the various light sources. If the lamps are of different candle-power, the illumination may be determined by combining the illumination from each source as calculated separately. An example of calculation is given under "Arrangement of Lamps."

The above method is not strictly accurate because it does not take account of the angle at which the light from each one of the sources strikes the assumed plane of illumination. If the ray of light is perpendicular to the plane, the formula $I = \frac{c.p.}{d^2}$ gives correct values. If a is the angle which the ray of light makes with a line drawn from the light source perpendicular to the assumed plane, then the formula becomes $I = \frac{c.p. \times \text{cosine } a}{d^2}$. Therefore, by multiplying the candle-power value of each light source in the direction of the illuminated point by the cosine of each angle a, a more accurate result will be obtained.

It is readily seen that the effect of reflected light from the ceilings is of more importance than that from the floor of a room. The value of k, in the above formula, will vary from 60% to 10%, but for rooms with a fairly light finish 50% may be taken as a good average value.

The amount of illumination will depend on the use to be made of the room. One foot-candle gives sufficient illumination for easy reading, when measured normal to the page, and probably an illumination of .5 foot-candle on a plane 3 feet from the floor forms a sufficient ground illumination. The illumination from sunlight reflected from white clouds is from 20 foot-candles up, while that due to moonlight is in the neighborhood of .03 foot-candles. It is not possible to produce artificially a light equivalent to daylight on account of the great amount of energy that would be required and the difficulty of obtaining proper diffusion.

The method of calculating the illumination of a room that has just been described is known as the *point-by-point* method and it gives very accurate results if account is taken of the angle at which the light from each source strikes the plane of illumination and if the light distribution curves of the units, and the value of k, have been carefully determined. Under these conditions the calculations become extended and complicated and methods only approximate, but simpler in their application, are being introduced. One method, which gives good results when applied to fairly large interiors, makes the flux of light from the light sources the basis of calculation of the average illumination.

Flux of light is measured in lumens and a *lumen* may be defined as the amount of light which must fall on one square foot of surface in order to produce a uniform illumination of an intensity of one foot-candle. A source of light giving one candle-power in every direction and placed at the center of a sphere of one foot radius would give an illumination of one foot-candle at every point in the surface of the sphere and the total flux of light would be 4π, or 12.57, lumens since the area of the sphere would be 4π, or 12.57, sq. ft. A lamp giving one mean spherical candle-power gives a flux of 12.57 lumens and the total flux of light from any source is obtained by multiplying its mean spherical candle-power by 12.57. In calculating illumination it is customary to determine the illumination on a plane about 30 inches from the floor for desk work, and about 42 inches from the floor for the display of goods on counters. If we determine the total number of lumens falling on this plane and divide this number by the area of the plane, we obtain the average illumination in foot-candles. This of course tells us nothing about the maximum or minimum value of the illumination and such values must be obtained by other methods if they are desired. Reflected light, other than that covered by the distribution curve of the light unit including its reflector, is usually neglected in this method of calculation.

We may assume that in large rooms the light coming from the lamp within an angle of 75 degrees from the vertical reaches the plane of illumination. In smaller rooms this angle should be reduced to about 60 degrees. In order to determine the flux of light within this angle a Rousseau diagram, which is described later, should be drawn. By the means of this diagram the average candle-power of the light source within the angle assumed may be readily determined and this mean value, multiplied by 12.57, will give the flux of light in lumens. This method of calculation, together with some guides for its rapid application, is described by Messrs. Cravath and Lansingh in the "Transactions of the Illuminating Engineering Society, 1908." The same authorities give the following useful data:

To determine the watts required per square foot of floor area, multiply the intensity of illumination desired by the constants given as follows:

INTENSITY CONSTANTS FOR INCANDESCENT LAMPS

Tungsten lamps rated at 1.25 watts per horizontal candle-power; clear prismatic reflectors, either bowl or concentrating; large room; light ceiling; dark walls; lamps pendant; height from 8 to 15 feet	.25
Same with very light walls	.20
Tungsten lamps rated at 1.25 watts per horizontal candle-power; prismatic bowl reflectors enameled; large room; light ceiling; dark walls; lamps pendant, height from 8 to 15 feet	.29
Same with very light walls	.23
Gem lamps rated at 2.5 watts per horizontal candle-power; clear prismatic reflectors either concentrating or bowl; large room; light ceiling; dark walls; lamps pendant; height from 8 to 15 feet	.55
Same with very light walls	.45
Carbon filament lamps rated at 3.1 watts per horizontal candle-power; clear prismatic reflectors either bowl or concentrating; light ceiling; dark walls; large room; lamps pendant; height from 8 to 15 feet	.65
Same with very light walls	.55
Bare carbon filament lamps rated at 3.1 watts per horizontal candle-power; no reflectors; large room; very light ceiling and walls; height from 10 to 14 feet	.75 to 1.5
Same; small room; medium walls	1.25 to 2.0
Carbon filament lamps rated at 3.1 watts per horizontal candle-power; opal dome or opal cone reflectors; light ceiling; dark walls; large room; lamps pendant; height from 8 to 15 feet	.70
Same with light walls	.60

INTENSITY CONSTANTS FOR ARC LAMPS

5-ampere, enclosed, direct-current arc on 110-volt circuit; clear inner, opal outer globe; no reflector; large room; light ceiling; medium walls; height from 9 to 14 feet	.50

Arrangement of Lamps. An arrangement of lamps giving a uniform illumination cannot be well applied to residences on account of the number of units required, and the inartistic effect. We are limited to chandeliers, side lights, or ceiling lights, in the majority of cases, with table or reading lamps for special illumination.

When ceiling lamps are used and the ceilings are high, some form of reflector or reflector lamp is to be recommended. In any case where the coefficient of reflection of the ceilings is less than 40%, it is more economical to use reflectors. When lamps are mounted on chandeliers, the illumination is far from uniform, being a maximum in the neighborhood of the chandelier and a minimum at the corners of the room. By combining chandeliers with side lights it is generally possible to get a satisfactory arrangement of lighting for small or medium-sized rooms.

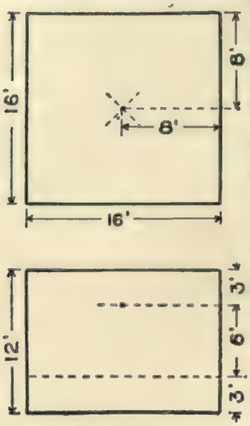


Fig. 53. Diagram Showing Method of Calculating Room Illumination.

As a check on the candle-power in lamps required, we have the following:

For brilliant illumination allow one candle-power per two square feet of floor space. In some particular cases, such as ball rooms, this may be increased to one candle-power per square foot.

For general illumination allow one candle-power for four square feet of floor space, and strengthen this illumination with the aid of special lamps as required. The location of lamps and the height of ceilings will modify these figures to some extent.

As an example of the calculation of the illumination of a room with different arrangements of the units of light, assume a room 16 feet square, 12 feet high, and with walls having a coefficient of reflection of 50%. Consider first the illumination on a plane 3 feet above the floor when lighted by a single group of lights mounted at the center of the room 3 feet below the ceiling. If a minimum value of .5 foot-candle is required at the corner of the room, we have the equation (first method outlined):

$$.5 = c.\ p. \frac{1}{12.8^2} \times \frac{1}{1 - .5}$$

Since $d = \sqrt{8^2 + 8^2 + 6^2} = 12.8$ (see Fig. 53)

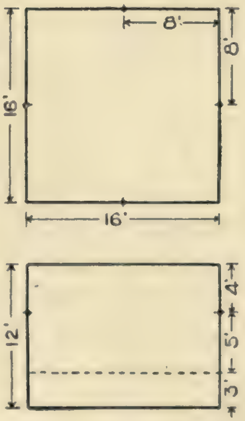


Fig. 54. Diagram for Four 8-c. p. Lamps on Side Wall.

Solving the above for the value of *c. p.*, we have

$$c.\,p. = \frac{.5}{\frac{1}{164} \times \frac{1}{.5}} = .5 \times 82 = 41$$

Three 16-candle-power lamps would serve this purpose very well.

Determining the illumination directly under the lamp, we have:

$$I = 48 \times \frac{1}{6^2} \times \frac{1}{1 - .5} = \frac{48}{36} \times 2 =$$

2.7 foot-candles, or five times the value of the illumination at the corners of the room.

Next consider four 8-candle-power lamps located on the side walls 8 feet above the floor, as shown in Fig. 54. Calculating the illumination at the center of the room on a plane three feet above the floor, we have:

$$I = 8\left(\frac{1}{89} + \frac{1}{89} + \frac{1}{89} + \frac{1}{89}\right) \frac{1}{1 - .5}$$

$$d^2 = 8^2 + 5^2 = 64 + 25 = 89$$

$$I = 8 \times \frac{4}{89} \times 2 = .72 \text{ foot-candles}$$

The illumination at the corner of the room would be:

$$I = 8\left(\frac{1}{89} + \frac{1}{89} + \frac{1}{345} + \frac{1}{345}\right) \frac{1}{1 - .5}$$

$$= 8\left(\frac{2}{89} + \frac{2}{345}\right) \times 2 = .45 \text{ foot-candles.}$$

In a similar manner the illumination may be calculated for any point in the room, or a series of points may be taken and curves plotted showing the distribution of the light, as well as the areas having the same illumination. Where refined calculations are desired, the distribution curve of the lamp must be used for determining the candle-power in different directions. Fig. 55 shows illumination curves for the Meridian lamp as manufactured by the General Electric Company. This is a form of reflector lamp made in two sizes, 25 or 50 candle-power. Fig. 56 gives the distribution curves for the 50-candle-power unit. Similar incandescent lamps are now being manufactured by other companies.

Table XIV gives desirable data in connection with the use of the Meridian lamp.

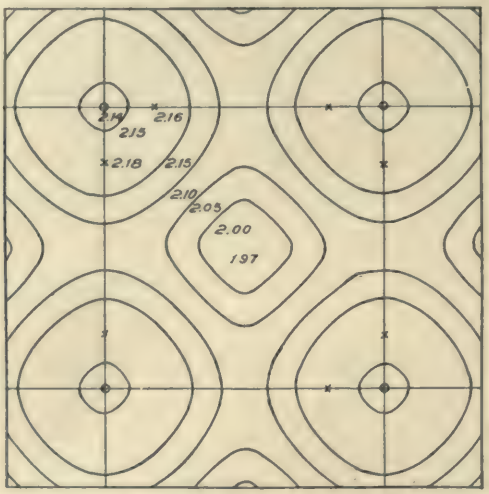


Fig. 55. Illumination Curves for a G. E. Meridian Lamp.

TABLE XIV
Illuminating Data for Meridian Lamps

Class Service	Light Intensity in Foot-candles	No. 1 Lamp (60 Watts)		No. 2 Lamp (120 Watts)		Watts per Sq. Ft. of Area Lighted with either Lamp
		Height of Lamp and Diameter of Uniformly Lighted Area	Distance between Lamps when Two or more are Used	Height of Lamp and Diameter of Uniformly Lighted Area	Distance between Lamps when Two or more are Used	
Desk or Reading Table	3	2.9 feet	4.9 feet	4 feet	7 feet	2.50
	2	3.5 "	6 "	5 "	8.5 "	1.66
	1½	4 "	7 "	5.75 "	9.8 "	1.25
General Lighting	1	5 "	8.5 "	7 "	12 "	0.83
	¾	5.75 "	9.8 "	8.2 "	13.9 "	0.62
	½	7 "	12 "	10 "	11 "	0.41

By means of the Weber, or some other form of portable photometer, curves as plotted from calculations may be readily checked after the lamps are installed. When lamps are to be permanently located, the question of illumination becomes an important one, and it may be desirable to determine, by calculation, the illumination curves for each room before installing the lamps. This applies to the lighting of large interiors more particularly than to residence lighting. The point-by-point method of calculation is used for very accurate work when the system of illumination admits of this method. Other methods are often simpler and sufficiently accurate for practical work.

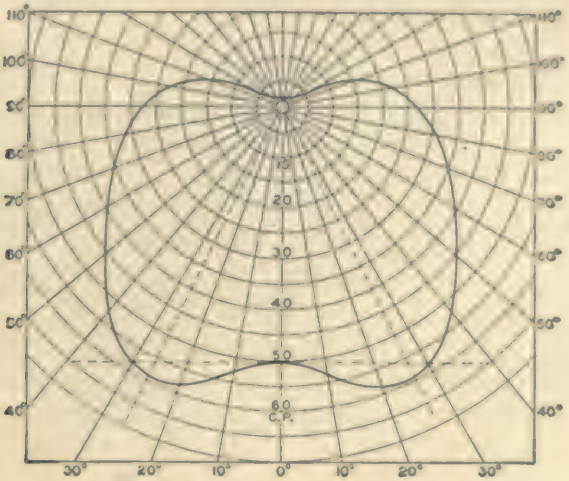


Fig. 56. Distribution Curve for a G. E. 50-c. p. Meridian Lamp.

Dr. Louis Bell gives the following in connection with residence lighting:

TABLE XV

Residence Lighting Data

Room	8 C. P.	16 C. P.	32 C. P.	Sq. ft per C.P.	Remarks
Hall, 15′ × 20′	8			4.7	
Library, 20′ × 20′	12		1	3.1	8-c.p. reflector lamps
Reception room, 15′ × 15′	4			7.0	
Music room, 20′ × 25′	12		2	3.0	
Dining room, 15′ × 20′	14			2.7	8 reflector lamps
Billiard room, 15′ × 20′			4	2.3	32-c.p. with reflectors
Porch			1		
Bedrooms (6), 15′ × 15′		14		7.0	
Dressing rooms (2), 10′ × 15′		4		4.7	
Servants' rooms (3), 10′ × 15′		3		9.4	
Bathrooms (3), 8′ × 10′		3		5.0	
Kitchen, 15′ × 15′ Pantry, 10′ × 15′		3			
Halls Cellar	10	3			
Closets (4)	4				Reflector lamps
Total	64	30	8		

LIGHTING OF PUBLIC HALLS, OFFICES, ETC.

Lighting of public halls and other large interiors differs from the illumination of residences in that there is usually less reflected light, and, again, the distance of the light sources from the plane of illumination is generally greater if an artistic arrangement of the lights is to be brought about. This in turn reduces the direct illumination. The primary object is, however, as in residence lighting, to produce a fairly uniform ground illumination and to superimpose a stronger illumination where necessary. An illumination of .5 foot-candle for the ground illumination may be taken as a minimum.

In the lighting of large rooms it is permissible to use larger light units, such as arc lamps and high candle-power Nernst or incandescent units, while for factory lighting and drafting rooms, where the color of the light is not so essential, the Cooper-Hewitt lamp is being introduced. High candle-power reflector lamps, such as the tungsten lamp, are being used to a large extent for offices and drafting rooms.

The choice of the type of lamp depends on the nature of the work. Where the light must be steady, incandescent or Nernst lamps are to be preferred to the arc or vapor lamps, though the latter are often the more efficient. When arcs are used, they must be carefully shaded so as to diffuse the light, doing away with the strong shadows due to portions of the lamp mechanism, and to reduce the intrinsic brightness. Such shading will be taken up under the heading "Shades and Reflectors." Arcs are sometimes preferable to incandescent lamps when colored objects are to be illuminated, as in stores and display windows.

In locating lamps for this class of lighting, much depends on the nature of the building and on the degree of economy to be observed. For preliminary determination of the location of groups, or the illumination when certain arrangement of the units is assumed, the principles outlined under "Residence Lighting" may be applied. It has been found that actual measurements show results approximating closely such calculated values.

When arcs are used they should be placed fairly high, twenty to twenty-five feet when used for general illumination and the ceilings are high. They should be supplied with reflectors so as to utilize the light ordinarily thrown upwards. When used for drafting-room work, they should be suspended from twelve to fifteen feet above the floor, and special care must be taken to diffuse the light.

Incandescent lamps may be arranged in groups, either as side lights or mounted on chandeliers, or they may be arranged as a frieze running around the room a few feet below the ceiling. The last named arrangement of lights is one that may be made artistic, but it is uneconomical and when used should serve for the ground illumination only. Reflector lights may be used for this style of work and the lights may be entirely concealed from view, the reflecting property of the walls being utilized for distributing the light where needed.

Ceiling lights should preferably be supplied with reflectors, especially when the ceilings are high.

Indirect lighting is employed to some extent. By indirect lighting we mean a system af illumination in which the light sources are concealed and the light from them is reflected to the room by the walls, or ceilings, or other surfaces; or in which the light sources are placed above a diffusing panel. In the latter case the diffusing plate appears to be the source of light. In some cases the walls themselves are shaped and constructed so as to form the reflectors for the light units (cove lighting), but in others all of the reflecting surfaces, except the side walls and ceiling, are made portions of the lamp fixtures.

Tables XVI and XVII give data on arc and mercury-vapor lamps for lighting large rooms. Table XVII refers to arc lights as actually installed.

TABLE XVI

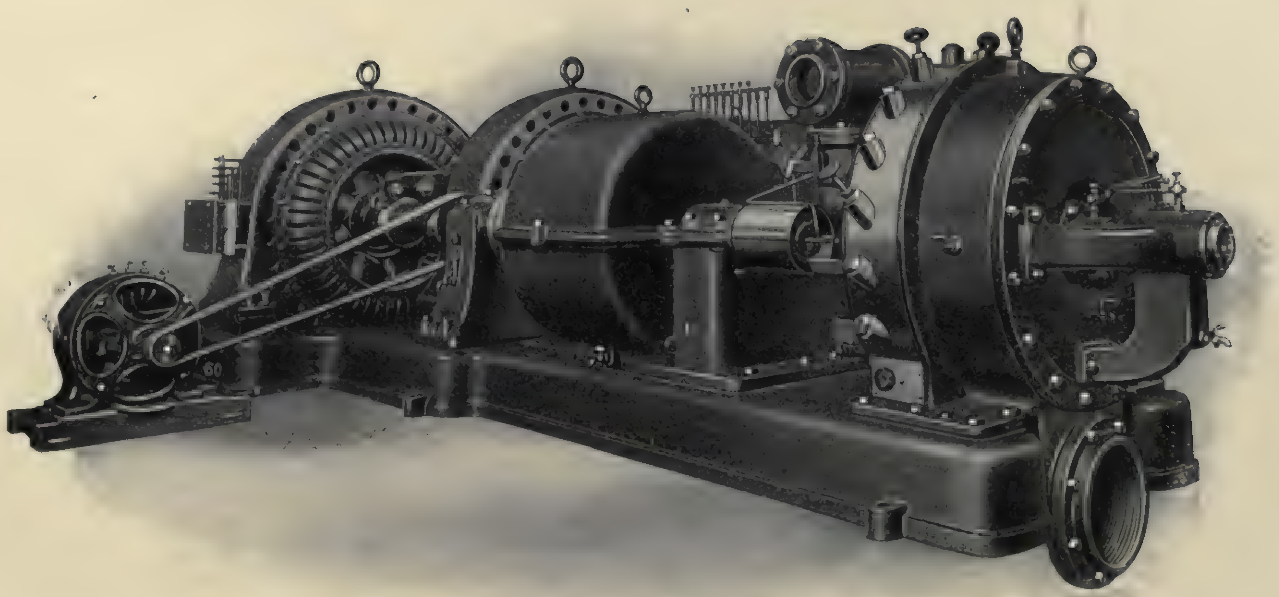
Cooper-Hewitt Lamps

SERVICE	HEIGHT OF LAMP	C. P. OF UNIT	AV. AREA PER LAMP IN SQUARE FEET
Foundry	10–15 ft.	300	900
"	20–25 "	700	2250
Machine shop	10–15 "	300	500
Erecting shop	20–30 "	700	1250
Drafting room	15 "	300	300
" "	20 "	700	400
Offices	10–15 "	300	400
"	20–25 "	700	750
Ordinary labor	10–15 "	300	1100
" "	20–25 "	700	2750

TABLE XVII

Lighting Data for Arc Lamps

PLACE LIGHTED	CLOTHING STORE	WEAVE ROOM	ERECTING ROOM	MACHINE SHOP	DRAFTING ROOM	DRAFTING ROOM	SHIP SHED	CATALOGING DEPT.	JEWELRY STORE
No. of sq. ft. place lighted	4000	14400	281600	42250	6275	5690	69000	4136	4000
No. lamps used	12	50	200	42	27	24	50	17	6
Circuit	A. C. Mult.	D. C. Mult.	D. C. Mult.	D. C. Mult.	A. C Series	D. C. Mult.	D. C. Mult.	D. C. Mult.	D. C. Mult.
Cycles	60	......	......	......	60	......	......	......	......
Volts line	104	110	120	120	......	120	220	110	110
Amperes	6	3¼	6.2	6.2	7.5	4	6	4½	5
Volts at arc	72	75	80	80	72	80	80	80	80
Power factor of lamp	.69	......	......	......	.86	......	......	......	......
Watts per lamp	430	357	744	744	490	480	660	495	550
Watts per sq. ft. (term.)	1.29	1.24	.53	.74	2.11	2.02	.478	2.03	.825
Kw. at term. (whole installation)	5.16	17.8	148.8	31.25	13.22	11.52	33	8.42	3.3
Kw. at arc (whole installation)	4.62	12.28	99.2	20.8	12.42	7.68	24	6.12	2.4
Sq. ft. lighted per lamp	333	288	1408	1006	232	237	1380	243	667
Sq. ft. lighted per amp	55.6	88.6	227	162	31	59.2	230	54.1	133.5
Enclosing globe	Opal.		Opal.	Opal.	Opal.	Opal.		Opal.	Opal.
Height and style of ceiling	12′ white steel	Saw Toothed	Trussed	Trussed	12′ White	Trussed	160′ Trussed	13′ 9″ Maroon	16′ 10′ White
Reflector system used	Concentric Diffuser	Adjust. Diffuser	9″ Mirror	9″ Mirror	Concentric Diffuser	16 Adj.Dif. 8 Con.Dif.	12″ Mirror	Concentric Diffuser	Concentric Diffuser
Height of arc from floor	9′ 6″	12′ to 15′	46′	47′	9′	15′	150′	10′ 7″	13′ 2″
Distance between lamps	14′ to 18′	24′	32′ to 38′	30′ 9″	15′	12′ to 25′	17′ to 20′	14′ to 18′	16′ to 25′



STEAM TURBINE DRIVING ALTERNATOR.
With Belted Exciter,
DeLaval Steam Turbine Company.

Measurements taken in well-lighted rooms having a floor space of from 1,000 to 5,000 square feet show an average of 3 to 3.5 square feet per candle-power. About 2.5 square feet per candle-power should be allowed when brilliant lighting is required or the ceilings are very high, while 3.75 square feet per candle-power will give good illumination when lights are well distributed and there is considerable reflected light.

In factory and drafting room lighting, the lamps must be arranged to give a strong light where most needed, and located to prevent such shadows as would interfere with the work.

STREET LIGHTING

In studying the lighting of streets and parks, we find that, except in special cases, such as narrow streets and high buildings, there is no reflected light which aids the illumination aside from that due to special shades or reflectors on the lamp itself. Such reflectors are necessary if the light ordinarily thrown above the horizontal plane is to be utilized.

In calculating the illumination due to any type of lamp at a given point it is necessary to know the distribution curve of the lamp used and the distance to the point illuminated. The approximate illumination of a plane normal to the rays of light is given by the formula,

$$I = \frac{c.p.}{h^2 + d^2}$$

when I = illumination in foot-candles.

c.p. = candle-power of the unit, determined from the distribution curve of the lamp.

h = distance the lamp is mounted above the ground, in feet, and d = distance from the base of the pole supporting the lamp to the point where the illumination is being considered, Fig. 57.

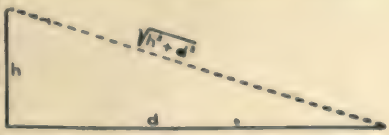


Fig. 57. Street Light Illumination Diagram.

While this will give the illumination in foot-candles, the nature of the lighting cannot be decided from this alone, but the total amount of light must also be considered. Thus, a street lighted with powerful units and giving a minimum illumination of .05 foot-candles would be considered better illuminated than one having smaller units so distributed as to give the same minimum value.

Since a uniform distribution of light is desirable, for economic reasons, the ideal distribution curve of a lamp for street lighting would be a curve which shows a low value of candle-power thrown directly downward, but with the candle-power increasing as we approach the horizontal. Such an ideal distribution curve is shown in Fig. 58.

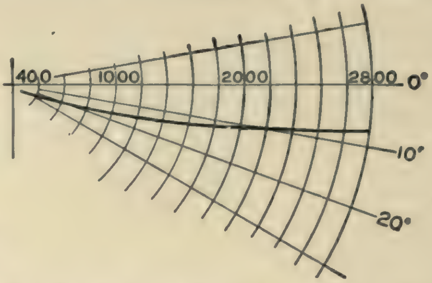


Fig. 58. Ideal Distribution Curve for a Street Light.

Actual distribution curves taken from commercial arc lamps are given in Fig. 59, in which

Curve *A* shows distribution curve for a 9.6-ampere, open, direct-current arc.

Curve *B* shows distribution curve for a 6.6-ampere, D.C. enclosed arc

Curve *C* shows distribution curve for a 7.5-ampere, A.C. enclosed arc.

Globes used with *B* and *C* are opal inner globes, clear outer globes.

Globes used with *A* are clear outer globes.

A street reflector was used with the enclosed arcs.

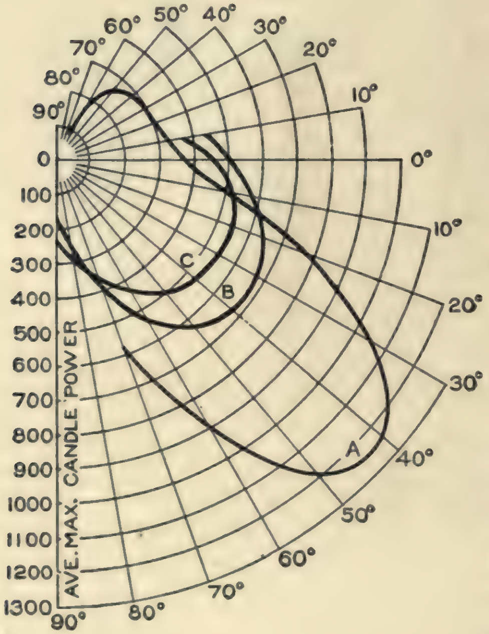


Fig. 59. Distribution Curves for Commercial Arc Lamps Used in Street Lighting.

Typical curves for flaming and luminous arc lamps are shown in Figs. 40, 43, and 44.

A series of curves known as *illumination curves* may be readily calculated showing the illumination in foot-candles at given distance from the foot of the pole supporting the lamp. Illumination curves corresponding to the distribution curves in Fig. 59 are given in Fig. 60 where *A′*, *B′*, and *C″* correspond to *A*, *B*, and *C* in Fig. 59. These curves correspond to actual readings taken with commercial lamps. Similar curves for incandescent lamps fitted with suitable reflectors are shown in Fig. 61. A value of .03 foot-candles is about the minimum for street lighting. Open arcs should be placed at least 25 feet above the ground; 30 to 40 feet is better, especially if the space to be illuminated is quite open. With enclosed arcs it is often advantageous to place them as low as 18 to 20 feet from the ground. Table XVIII gives the distance between lights for different types of arcs for fair illumination.

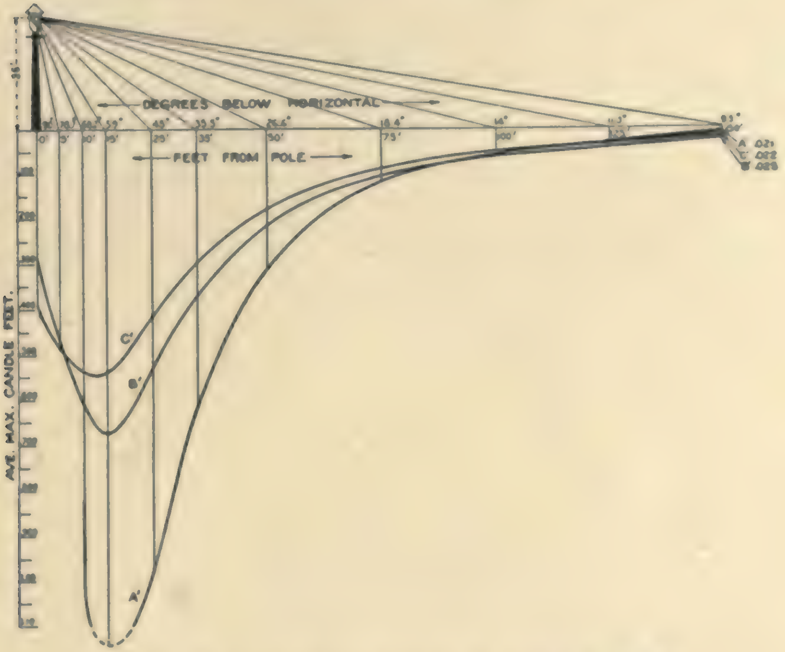


Fig. 60. Illumination Curves Drawn to Data given in Fig. 59.

In considering the type of arc light to be used we must turn to the illumination curves as shown in Fig. 60. These curves show that the illumination from a direct-current open arc in its present form is superior to that from a direct-current enclosed arc, taking the

TABLE XVIII

Kind of Light	Distance Between Lights	Lights per Mile
6.6-ampere enclosed D.C. arc	340 feet	15
9.6-ampere open D.C. arc	315 "	17
6.6-ampere enclosed A.C. arc	275 "	19
6.6-ampere open D.C. arc	260 "	20

same amount of power, in the vicinity of the pole; but at a distance of 100 feet, the illumination from the enclosed arc is better. This illumination is still more effective on account of the absence of such strong light as is given by the open arc near the pole. The pupil of the eye adjusts itself to correspond to the brightest light in the field of vision, and we are unable to see as well in the dimly-lighted section as when the maximum intensity is less. The characteristics of the open and enclosed direct-current arc lamps are as follows:

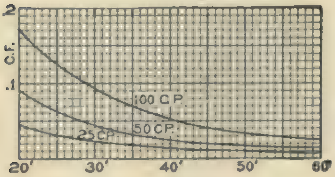


Fig. 61. Illumination Curves for Street Incandescent Lamps.

The mean spherical candle-power and energy required at the arc are variable with the open arc.

Fluctuations of light are marked, due to wandering of the arc, flickering due to the wind and lack of uniformity of the carbons.

Dense shadows are cast by the side rods and the lower carbon, while the light is objectionably strong in the vicinity of the pole.

With the enclosed arc the mean spherical candle-power and the watts consumed at the arc are fairly constant.

No shadows are cast by the lamps, and the illumination is not subject to such wide variations. The enclosed arc is much superior to the open arc using the same amount of energy. This applies to the open arc as it is now used. With proper reflection and diffusion of the light such as might be accomplished by extensive or special shading, we ought to be able to get as good distribution from the open arc with a greater total amount of illumination.

In comparing the direct-current with the alternating-current enclosed arc, we see that the direct-current arc gives slightly more light than the alternating lamp, but this may be more than counterbalanced by the better distribution of light from the alternating-current lamp. The selection of A.C. or D.C. enclosed lamps will usually depend on other conditions, such as method of distribution of power, efficiency of plant, etc.

TABLE XIX

Street-Lamp Data

Lamp	Amperes	Approx Watts at Lamp Terminals	Approx. Value of X as Proposed
D. C. Series, open arc, clear globe	6.6	330	3.5
	9.6	450	4
D. C. Series, enclosed, clear outer globe	5.0	370	3.5
	6.6	480	4
Opalescent inner globe, street reflectors	5.5	345	3
	6.6	430	3.5
	7.5	480	4
A. C. Series as above			
D. C. Series "Magnetite"	4.0	310	5.5

The question of street lighting has been given considerable attention by the National Electric Light Association and this society recommends the following form of specification for street lights:

1. Under ordinary conditions of street lighting, with lamps spaced 200 to 600 feet apart, specifications for street lamps should define the mean illumination thrown by the individual lamp, in position in the street, as measured at the height of the observer's eye and perpendicular to the rays, at some point not less than 200 feet nor more than 300 feet distant, along a level street, from a position immediately below the lamp, with all extraneous light screened off and with no reflection from surrounding objects not forming part of the lamp equipment.

2. When using smaller units of light, such as series incandescent lamps spaced shorter distances apart, a correspondingly shorter distance from the lamp should be chosen in measuring the illumination.

3. The lamp contracted for should give a mean normal illumination at the test point (selected as in Sections 1 and 2) not less than the illumination given by the stationary standard incandescent lamp of 16 candle-power at 1/X of the distance. The said standard incandescent lamp should be a standardized seasoned lamp having a determined candle-power in a fixed direction.

4. When the lamp tested fluctuates in intensity, a number of observations of the maximum normal illumination should be made at a distance of not less than 200 feet horizontally from beneath the lamp, and the average of these measurements should be taken as the average maximum illumination. A similar number of observations of the minimum normal illumination should be made, the average of which should be taken as the average minimum illumination. The arithmetical mean of the said average maximum and minimum illuminations should be taken as the mean normal illumination called for in Section 1.

5. A reasonable number of the lamps covered by the contract should be tested.

6. For measuring the mean normal illumination of a lamp, comparison with the standard incandescent lamp may be made either with a suitable portable

photometer or with a reading distance instrument, such as the so-called *luminometer*.

7. The unobstructed mean normal illumination must not be less at shorter distances than at the point of test.

8. An approximate value of the mean normal illuminations thrown by street lamps of standard manufacture, at horizontal distances within the 200–300-foot range, hung approximately 20 feet above the observer's eye, may be determined from Table XIX.

Series incandescent lamps are used considerably for lighting the streets in residence sections of cities or where shade trees make it impracticable to use arcs. These vary in candle-power from 16 to 50 or even higher, and are usually constructed so as to take from two to four amperes. The best arrangement of these is to mount them on brackets a few feet from the curb, with alternate lamps on opposite sides of the street. The distance between the lamps depends on their power. 50 candle-power lamps spaced 100 feet between lamps, give a minimum illumination of .02 foot-candle. 25 candle-power lamps spaced 75 feet between lamps will serve where economy is necessary.

TABLE XX

	Per Cent
Clear glass	10
Alabaster glass	15
Opaline glass	20–40
Ground glass	25–30
Opal glass	25–60
Milky glass	30–60
Ground glass	24.4
Opal glass	32.2
Opaline glass	23

SHADES AND REFLECTORS

Lamps, as ordinarily constructed, do not always give a suitable distribution of light, while the intrinsic brightness is often too high for interior lighting. Shades are intended to modify the intensity of the light, while reflectors are used for the purpose of changing its direction. Frequently the two are combined in various ways. Shades are also used for decorative purposes, but, if possible, these should be of such a nature as to aid illumination rather than to reduce its efficiency.

A considerable amount of light is absorbed by the material used for the construction of shades. Table XX shows the approximate amount absorbed by some materials.

Of the great number of styles of shades and reflectors in use, only a few of the more important will be considered here.

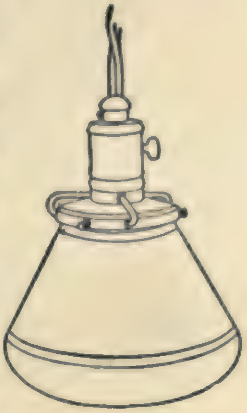
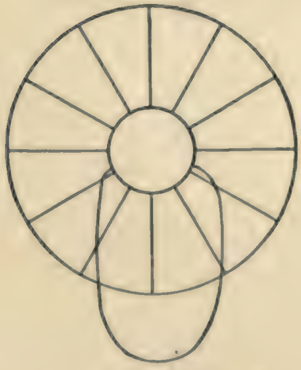


Fig. 62. McCreary Shade.

Frosted Globes. One of the simplest methods of shading incandescent lamps is by the use of frosted bulbs. These serve to reduce the intrinsic brightness of the lamp, and should be freely used for residence lighting when separate shades are not installed. Frosted globes are also used in connection with reflectors for the purpose of diffusing the reflected light. The *McCreary shade* as shown in Fig. 62, is an example of such a combined shade and reflector. Fig. 63 shows the distribution curve taken from an incandescent lamp using a McCreary shade. Fig. 64 shows the distribution of light from a conical shade. Fig. 56 shows the distribution of light brought about by means of a spiral filament and a reflector as used in the Meridian lamp.



43 C.P.

Fig 63. Distribution Curve for Incandescent Lamp Provided with McCreary Shade.

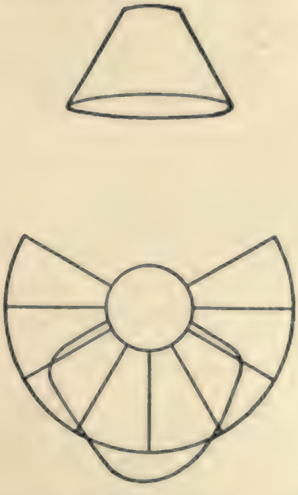


Fig. 64. Distribution Curve for Incandescent Lamp Provided with Conical Shade.

Holophane Globes. These are made for both reflecting and diffusing the light, and they can be made to bring about almost any desired distribution with but a small amount of absorption of light. These consist of shades of clear glass having horizontal grooves forming surfaces which change the direction of light by refraction or total reflection as is necessary. The diffusion of light is effected by means of deep, rounded, vertical grooves on the interior surface of the globe. While these globes are of clear glass and absorb an amount of light corresponding to clear glass, the light is so well diffused that the filament of the lamp cannot be seen, and the globe appears as if made of some semi-transparent material. The holophane glassware is made in a large variety of artistic designs and for all types of incandescent lamps. By the proper selection of a reflector the distribution of the light of the unit used may be made that which is best suited to the particular case of lighting in hand. Figs. 9, 13, 14, 15, 16, 17, and 18 give some idea of what can be accomplished by these shades.

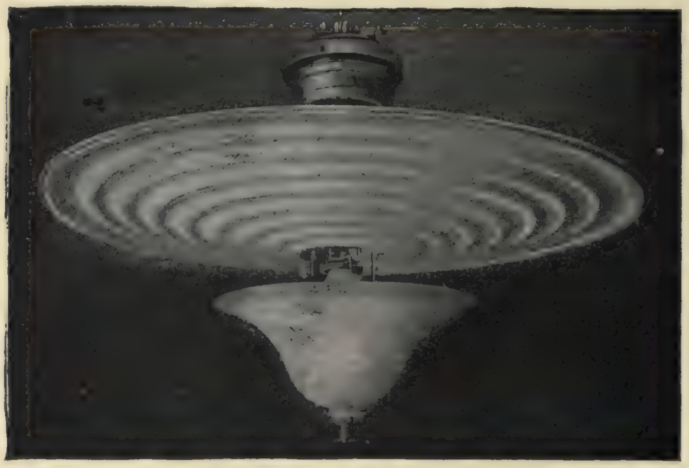


Fig. 65. Enclosed Arc Lamp Fitted with Shade and Concentric Diffuser.

Fig. 65 shows an enclosed arc lamp fitted with a shade and a concentric *diffuser*. The effect of this combination is best shown in Fig. 66. Fig. 67 shows the change in the illumination curve produced by such shading. Inverted arcs have some application where

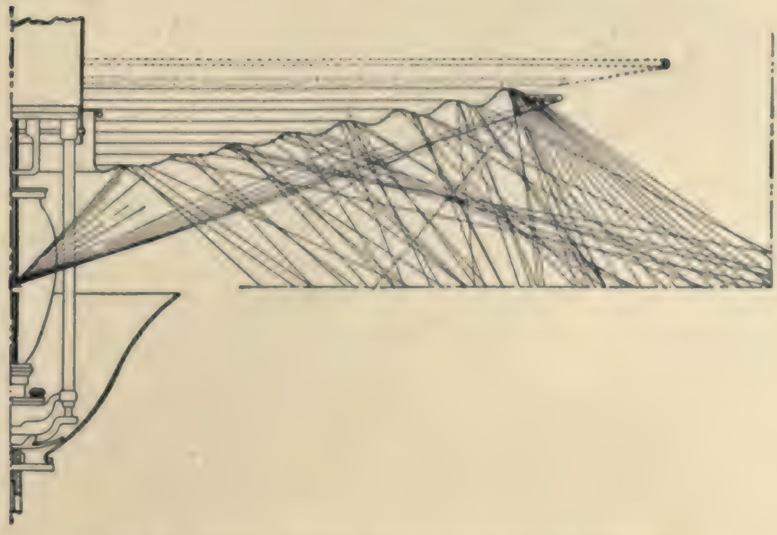


Fig. 66. Diagram Showing Effect of the Concentric Diffuser.

the light may be readily reflected and diffused as in lighting large rooms with light finish. Reflectors of this general type are now being manufactured in such a form that they may be built in and become part of the ceiling of the room to be illuminated.

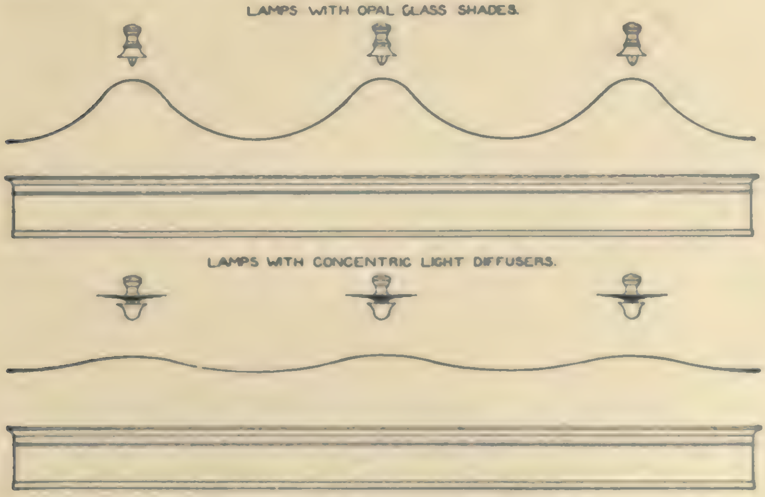

LAMPS WITH OPAL GLASS SHADES.
LAMPS WITH CONCENTRIC LIGHT DIFFUSERS.

Fig. 67. Illumination Curves for Lamps with and without Light Diffusers.

Opal Enclosing Globes. The use of opal enclosing globes is recommended for arc lamps used for street lighting for the reason that they change the distribution of the light so that it covers a greater area, and the light is so diffused as to obliterate shadows in the vicinity of the lamp. Table XXI gives the efficiency of different globe combinations for street lighting assuming the opal inner and the clear outer globes as 100%.

TABLE XXI

Opal enclosing and clear outer	100 per cent
Clear " " clear "	91.2 "
" " " opal "	85.1 "
Opal " " opal "	82.7 "

PHOTOMETRY

Photometry is the art of comparing the illuminating properties of light sources, and forms one branch of scientific measurement. Its use in electric illumination is to determine the relative values of different types of lamps as sources of illumination, together with their efficiency; also by means of the principles of photometry, we are able to study the distribution of illumination for any given arrangement of light sources.

LIGHT STANDARDS

Inasmuch as sources of light are compared with one another in photometry, we must have some standard, or unit, to which all light sources are reduced. This unit is usually the candle-power and the rating of most lamps is given in candle-power.

While the candle-power remains the unit and is based on the standard English candle, other light standards have been introduced and are much more desirable.

The English Candle. The English candle is made of spermaceti extracted from crude sperm oil, with the addition of a small quantity of beeswax to reduce the brittleness. Its length is ten inches, and its diameter .9 inch at the bottom and .8 inch at the top, and its weight is one-sixth of a pound. Great care is taken in the preparation of the wick and spermaceti. This candle burns with a normal height of flame of 45 millimeters and consumes 120 grains per hour when burning in dry air at normal atmospheric pressure. Under these conditions, the light given by a single candle is one candle-power.

When used for measurements, the candle should be allowed to burn at least fifteen minutes before taking any readings. At the end of this period the wick should be trimmed, if necessary, and when the flame height reaches 45 millimeters, readings can be taken. The candle should not require trimming when the proper height of flame has been reached. It is best to weigh the amount of material consumed by balancing the candle on a properly arranged balance when the first reading is taken, and again balancing at the end of a suitable period—ten to fifteen minutes. The candle-power of the unit is then, practically, directly proportional to the amount of the material consumed.

The objections to the candle as a unit are that it burns with an open flame which is subject to variation in height and to the effect of air currents. The color of the light is not satisfactory, being too rich in the red rays, and the composition of the spermaceti is more or less uncertain.

The German Candle is made of very pure paraffine, burns with a normal flame height of 50 millimeters, and is subject to the same disadvantages as the English candle. It may be necessary to trim the wick to keep the flame height at 50 millimeters. The light given is a trifle greater than for the spermaceti candle.

The Carcel Lamp is built according to very careful specifications and burns colza (rape seed) oil. It has been used to a large extent in France, but its present application is limited.

The Pentane Lamp is a specially constructed lamp burning pentane, prepared by the distillation of gasoline between narrow limits of temperature. This standard is not extensively used.

The Amyl Acetate Lamp. This lamp, known also as the *Hefner lamp*, is at present the most desirable standard. It is a lamp built to very careful specifications, especially with regard to the dimension of the wick tube. It burns pure amyl acetate and the flame height should be 40 millimeters. This flame height must be very carefully adjusted by means of gauges furnished with the lamp. Amyl acetate is a colorless hydrocarbon prepared from the distillation of amyl alcohol obtained from fusil oil, with a mixture of acetic and sulphuric acids, or by distillation of a mixture of amyl acetate, sulphuric acid, and potassium acetate. It has a definite composition, and must be pure for this use.

The most serious disadvantage of this standard is the color of the light, inasmuch as it has a decidedly red tinge and is not readily compared with whiter lights. Its value is affected somewhat by the moisture in the air and the atmospheric pressure, but it excels all other standards in that it is quite readily reproduced.

Table XXII gives the value of the candle-power units of different laboratories in terms of the unit of the Bureau of Standards and also the values of the units of the Carcel and Vernon-Harcourt in terms of the Hefner, as accepted by the International Photometric Commission.

TABLE XXII

Photometric Units

Bureau of Standards Unit, United States	1.000
Reichsanstalt Unit, Germany	0.998 × 0.88
National Physical Laboratory Unit, England	0.984
Laboratoire Central Unit, France	0.982

	Carcel	Hefner	Vernon-Harcourt
Carcel	1.00	10.75	0.980
Hefner	0.0930	1.00	0.0915
Vernon-Harcourt (pentane)	1.020	10.95	1.0

The above values are at a barometric pressure of 760 mm. of mercury and a humidity for the Carcel and Vernon-Harcourt standards of 10.0 liters of water per cubic meter of dry air. The humidity for the hefner unit is 8.8 liters of water to one cubic meter of dry air.

Working Standards. *Incandescent Lamp.* The units just described, together with some others, form reference standards, but an incandescent lamp is generally used as the working standard in all photometers. An incandescent lamp, when used for this work, should be burned for about two hundred hours, or until it has reached the point in the life curve where its value is constant, and it should then be checked by means of some standard when in a given position and at a fixed voltage. It then serves as an admirable working standard if the applied voltage is carefully regulated. Two such lamps should always be used—the one to serve as a check on the other; the checking lamp to be used for very short intervals only.

PHOTOMETERS

Two light sources are compared by means of a photometer which, in one of its simplest forms, consists of what is known as a *Bunsen screen* mounted on a carriage between the two lights being compared, with its plane at right angles to a line passing through the light sources, and arranged with mirrors or prisms so that both sides of the screen may be observed at once. The Bunsen screen consists of a disk of paper with a portion of either the center, or a section around the center, treated with paraffine so as to render it translucent. If the light falling on one side of this screen is in excess, the translucent spot will appear dark on that side of the screen and light on the opposite side. Care must be taken to see that the two sides of the screen are exactly alike, otherwise there will be an error introduced in using the screens. It is well to reverse the screen and check readings whenever a new lot of lamps are to be tested. When the light falling on the two sides of the screen is the same, the transparent spot disappears. The values of the two light sources are then directly proportional to the square of their distances from the screen. As an example, consider a 16 candle-power lamp being compared with a standard candle on a photometer with a 300-centimeter bar. Say the translucent spot disappears when the screen is distant 60 centimeters from the standard candle, we then have the proportion,

$$x : 1 = (240)^2 : (60)^2 = 16 : 1,$$

showing that the lamp gives 16 candle-power.

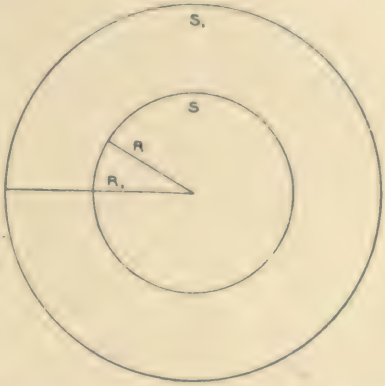


Fig. 68. Proof of the Law of Inverse Squares by the Method of Concentric Spheres.

The above law is known as the law of inverse squares, and holds true only when the dimensions of the light sources are small compared with the distance between them, and when there are no reflecting surfaces present as when the readings are taken in a dark room.

The proof that the light varies inversely with the square of distance from the source is as follows:

Consider two spherical surfaces, Fig. 68, illuminated by a source of light at the center. The same quantity of light falls on both surfaces.

Area of $S = 4\pi R^2$ sq. ft. (R is in feet.)
Area of $S_1 = 4\pi R^2_1$ sq. ft.

Let Q = total quantity of light and q = light falling on unit surface. Then,

$$q = \frac{Q}{4\pi R^2}$$

$$q_1 = \frac{Q}{4\pi R^2_1}$$

$$q : q_1 = \frac{Q}{4\pi R^2} : \frac{Q}{4\pi R^2_1}$$

$$= 4\pi R^2_1 : 4\pi R^2$$

$$\frac{q}{q_1} = \frac{R^2_1}{R^2}$$

Fig. 69 shows the relation in another way. The area of C, distant two units from the source of light A, is four times that of B which is distant one unit.

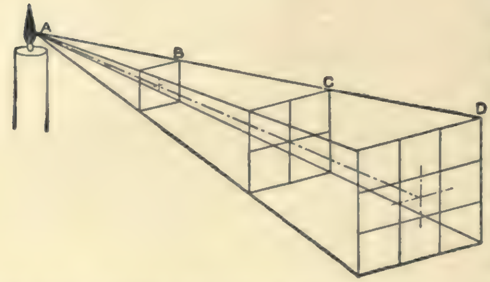


Fig. 69. Proof of the Law of Inverse Squares by Method of Screen Shadow.

The Lummer-Brodhun Photometer. In addition to the Bunsen screen described, there are several other forms of photometers, the most important of which is the Lummer-Brodhun. The essential feature of this instrument is the optical train which serves to bring into contrast the portions of the screen illuminated by the two sources of light. Referring to Fig. 70 the screen S is an opaque screen which reflects the light falling upon it from *L*, to the mirror *M*, when it is again reflected to the pair of glass prisms *A*, *B*. The surfaces *sr* are ground to fit perfectly and any light falling on this surface will pass through the prisms. Light falling on the surface *ar* or *bs* will be reflected as shown by the arrows. We see then that the light from *L*, which falls on *ar* and *bs*, is reflected to the eye piece or telescope *T*, while that falling on *sr* is transmitted to and absorbed by the black interior of the containing box. Likewise, the light from the screen L_1 is reflected by the screen M_1 to the pair of prisms *A*, *B*. The rays falling on the surface *sr* pass through to the telescope *T*, while the rays falling on *ar* and *bs* are reflected and absorbed by the black lining of the case. The field of light, as then viewed through the telescope, appears as a disk of light produced by the screen L_1, surrounded by an annular ring of light produced by *L*. When the illumination on the two sides of the screen is the same, the disk and ring appear alike and the dividing circle disappears.

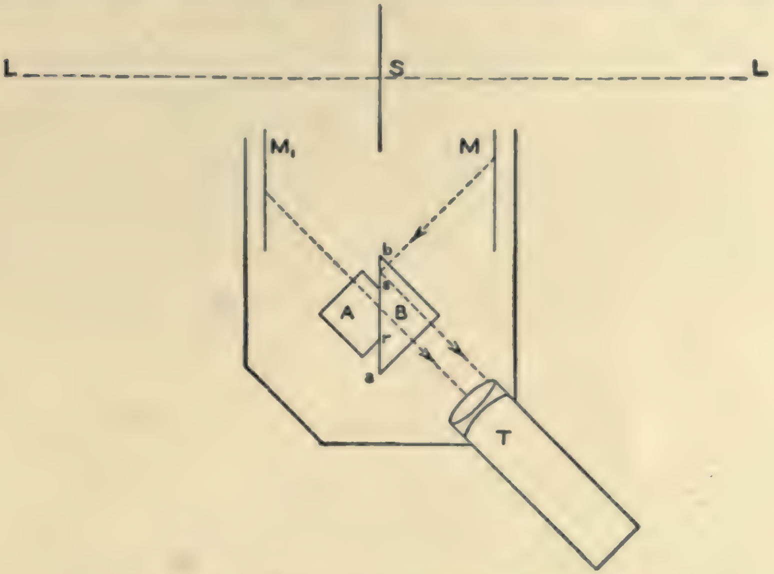


Fig. 70. Diagram of Lummer-Brodhun Screen.

In using this screen, it is mounted the same as the Bunsen screen and readings are taken in the same manner. The screen and prisms are arranged so that they can be reversed readily and two readings should always be taken to compensate for any inequalities in the sides of the screen and the reflecting surfaces, a mean of the two readings serving as the true reading. This form of screen is used when especially accurate comparisons are required.

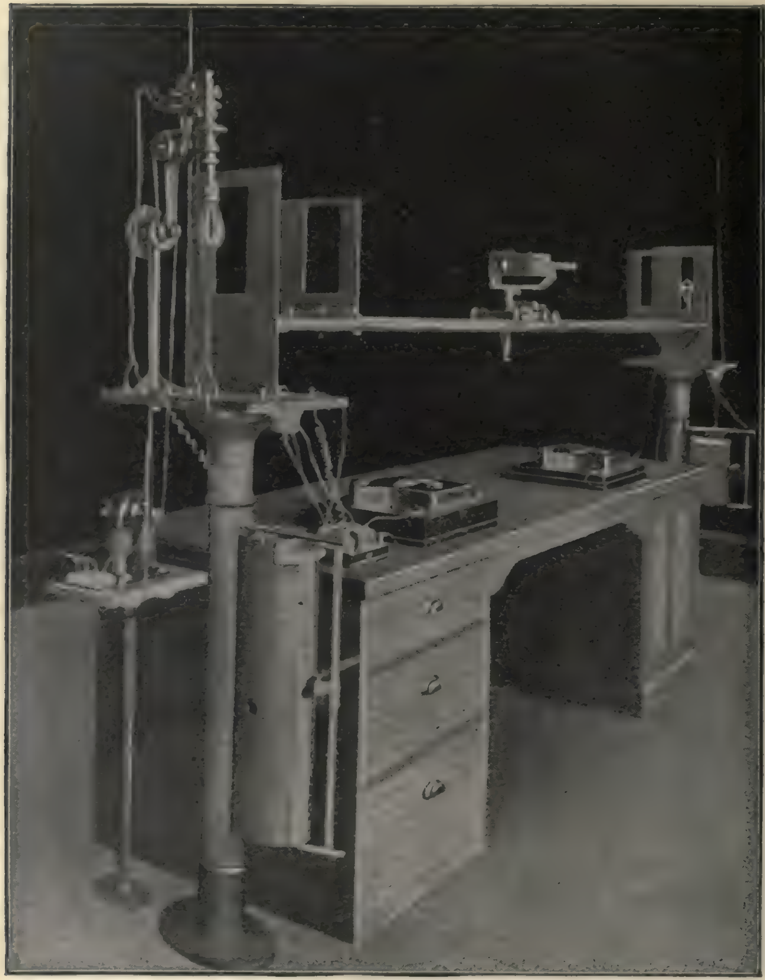
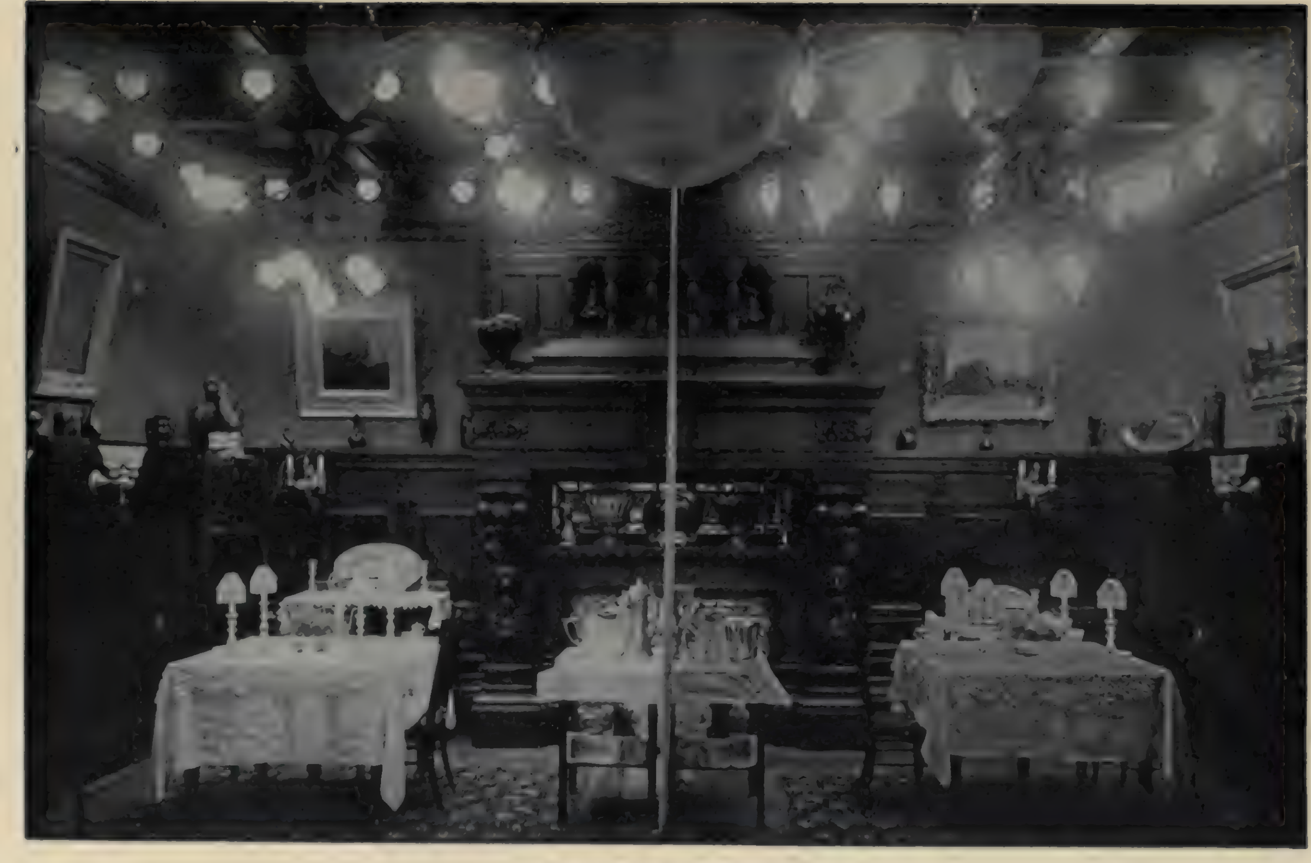


Fig. 71. Complete Photometer with Lummer-Brodhun Screen.

Fig. 71 shows a complete photometer with a Lummer-Brodhun screen, while Fig. 72 shows a Bunsen screen and sight box. In Fig. 71, the lamps are shaded by means of curtains so as to leave only a



HOLOPHANE EXHIBIT.

World's Fair, St Louis

small opening toward the screen. If the lights are properly screened photometric measurements may be made in rooms having light-colored walls.

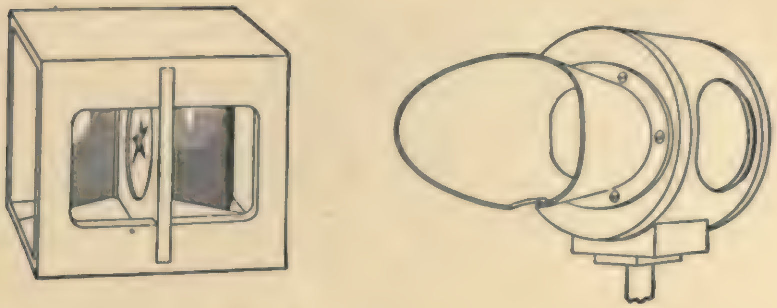


Fig. 72. Bunsen Screen and Sight Box.

The Weber Photometer. As an example of a portable type of photometer, we have the Weber. This photometer, shown in Fig. 73, is very compact and is especially adapted to measuring intensity of illumination as well as the value of light sources; it may be used for exploring the illumination of rooms or the lighting of streets.

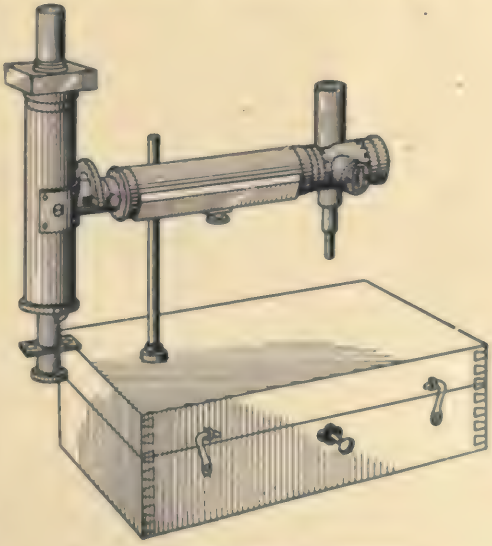


Fig. 73. Weber Portable Photometer.

This apparatus consists of a tube *A*, Fig. 74, which is mounted horizontally and contains a circular, opal glass plate *f*, which is movable by means of a rack and pinion. To this screen is attached an index finger which moves over a scale attached to the outside of the tube. A lamp *L*, burning benzine, is mounted at the end of this tube. The benzine used should be as pure as possible, and the flame height should be carefully adjusted to 20 mm. when taking readings. At right angles to the tube A is mounted the tube B which contains an eye piece at O, a Lummer-Brodhun contrast prism at p, and a support for opal or colored glass plates at g.

Operation. The tube B is turned toward the source of light to be measured, the distance from the light to the screen at g being noted. The light from this source is diffused by the screen at g, while that from the standard is diffused by the screen f. By moving the screen f, the light falling on either side of the prism p can be equalized. The value of the unknown source can be determined from the reading of the screen f, the photometer having previously been calibrated by means of a standard lamp in place of the one to be measured. The calibration may be plotted in the form of a curve or it may be denoted by a constant C, when we have the formula,

$$I' = C \frac{L^2}{l^2}$$

C corresponds to a particular plate at g, l = distance of screen f from the benzine lamp, and L = distance from the screen g to the light source being measured. Screens of different densities may be used at g, depending on the strength of the light source.

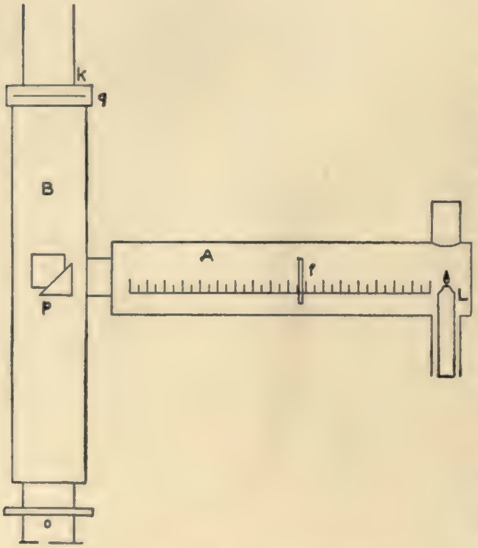


Fig. 74. Diagram of Weber Photometer.

When used for measuring illumination, a white screen is used in connection with this photometer. The screen is mounted in front of the opening at g, and turned so that it is illuminated by the source being considered. Readings of the screen f are taken as before. A calibration curve is plotted for the instrument, using a known light source at a known distance from the white screen when the instrument is mounted in a dark room.

Portable Photometers. There is a large variety of portable photometers available and giving more or less satisfactory results. An instrument especially designed with a view to portability and to overcoming some of the defects of instruments already on the market has recently been introduced. The instrument referred to is called a *Universal photometer* but it is more commonly known as the *Sharp-Millar photometer* from the names of its inventors. Views of this instrument are shown in Figs. 75 and 76. It is adapted to the measurement of the intensity of light sources as well as to the illumination at any point, as is the Weber photometer. The photometer screen or photometric device is shown at *B*, and consists of a special form of Lummer-Brodhun optical screen. A standardized incandescent lamp *C* is used as the photometric standard and this may be connected to a battery, or be adapted to use on the mains supplying the lamps in the room where measurements are to be taken. All stray light is carefully screened from the interior of the box by a series of screens *G*. The instrument scale is calibrated in foot-candles and in candle-powers.

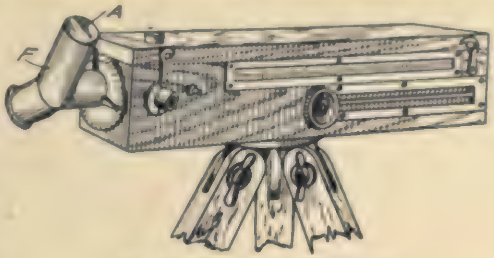


Fig. 75. Universal Photometer.

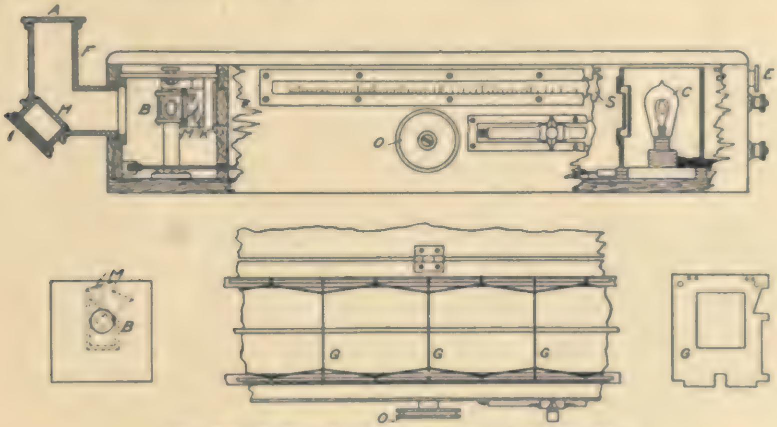


Fig. 76. Sectional View of Universal Photometer.

When illumination is to be measured, a specially selected transluscent screen is placed at *A* and the illumination of this plate, which is placed at the point and in the plane where the value of the illumination is desired, is reflected to the photometric device by the mirror at *H*. A second plate *K* is mounted so as to be illuminated by the standard lamp and the photometer is balanced by making the illumination of *A* and *K* the same. When the intensity of a light source is to be determined, the screen at *A* is replaced by a small aperture and a diffusing surface *I* is put in place of the mirror *H*. The illumination of *I* is now compared with the illumination of *K*, and when the two are made equal, the photometer reads the candle-power of the light source, or some multiple of this candle-power. The range of this instrument is increased by the use of suitably arranged absorbing screens which may be readily inserted or removed, and as ordinarily equipped, the range in foot-candles is approximately from .004 to 2,000. The variety of uses which can be made of such a photometer is large, and some idea of its portability can be obtained from the dimensions of the box, 24″ x 4½″ x 5″, and its weight, fully equipped, of 8 pounds. It is very accurate considering its compactness.

Integrating Photometers. *Matthews.* This photometer is used to some extent and a very good idea of its construction can be obtained from Fig. 77. By means of a system of mirrors, the light given by the lamp in several directions may be integrated and thrown on the photometer screen for comparison with the standard, the result giving the mean spherical candle-power from one reading. By covering all but one pair of screens, the light given in any one direction is easily determined.

Another type of integrating photometer is known as the *integrating sphere* or *globe photometer.* If a light source is placed within a sphere, the interior walls of which are coated with a white diffusing surface, the illumination of that surface at any point is due partly to the light falling on it directly, and partly to the light reflected from the remainder of the surface of the sphere. The reflected light is proportional to the total flux of light from the light source and so, if the direct light is screened from the point considered, its illumination is proportional to the total flux of light, and hence to the mean spherical candle-power of the light source.

The practical application of this principle is to so arrange our properly coated sphere that the lamp to be tested may be readily inserted; to replace a small portion of the sphere by a piece of unpolished white glass; to shut off the direct rays of the lamp to be measured from this glass surface; and to so mount a photometer screen and standard lamp that the illumination of the glass section can be measured. Under these conditions the illumination of the glass screen is proportional to the mean spherical candle-power of the lamp under test. A substitution method is used in practice. A

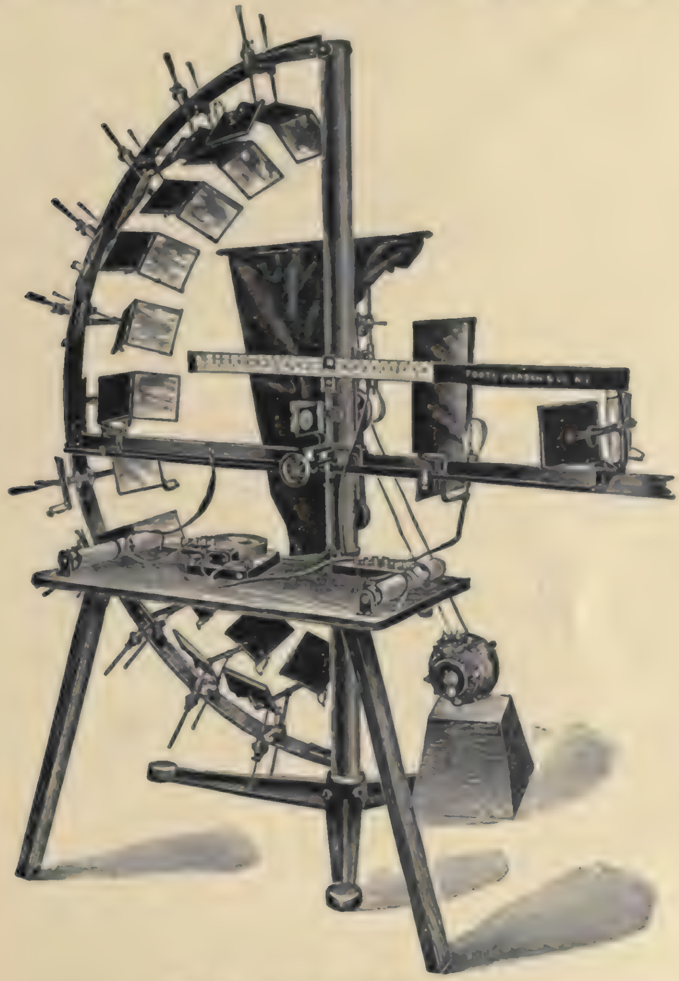


Fig. 77. Integrating Photometer.

standardized lamp of the general type of the one to be tested is mounted in the sphere and the constant of the instrument for this type of lamp is determined. The unknown lamps are then put in place and their candle-power is readily determined, once the constant of the instrument is known. Figs. 78 and 79 give some views of the integrating

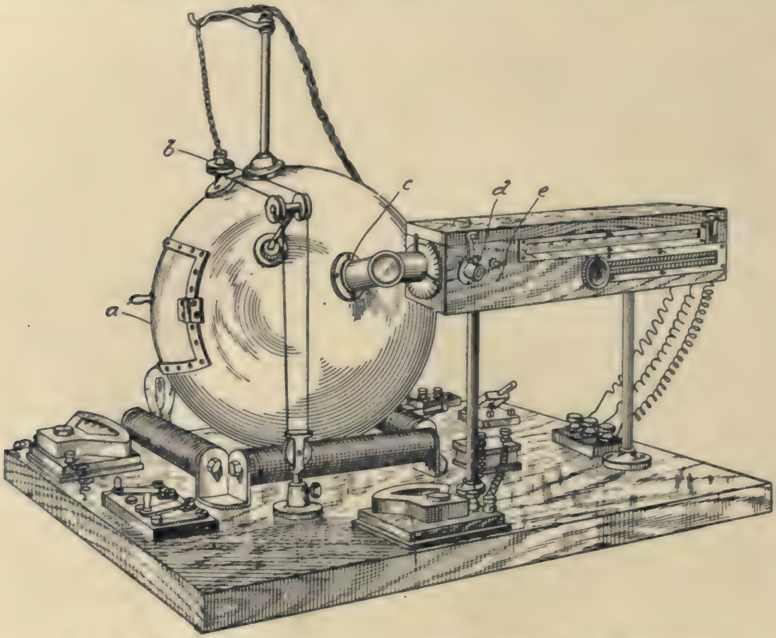


Fig. 78. Eighteen-Inch Integrating Sphere Equipped with Photometer.

sphere and indicate the range of the sizes in which it may be constructed.

INCANDESCENT LAMP PHOTOMETRY

Apparatus. Some sort of screen, either the Bunsen type or the Lummer-Brodhun screen preferred, should be mounted on a carriage moving on a suitable scale, and the lamp holders, one for the standard, the other for the lamp to be tested, are mounted at the ends of this scale. There are several types of so-called station photometers arranged so as to be very convenient for testing incandescent lamps. Fig. 80 shows one form of station photometer manufactured by Queen & Co. The controlling rheostats and shielding curtains are not shown here. Fig. 81 shows a form of portable photometer for incandescent lamps. The length of scale should not be less than 100 centimeters, and 150 to 200 centimeters is preferred. This scale may be divided into centimeters or, for the purpose of doing away with much of the calculation, the scale may be a *proportional scale*. This scale is based on the law of inverse squares and reads the inverse ratio of the squares of the distances from the two lights being compared.

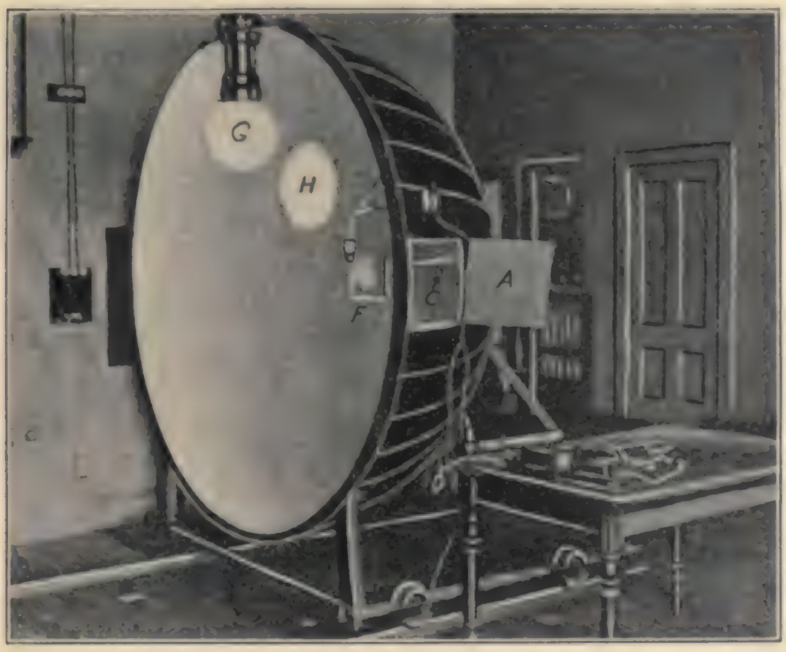


Fig. 79. Interior of 80-Inch Integrating Sphere.

If the standard used always has the same value, the scale may be made to read in candle-powers directly.

For mean horizontal candle-power measurements, the lamp should be rotated at 180 revolutions per minute, when mounted in a vertical position.

For distribution curves a universal lamp holder which will allow the lamp to be placed in any position, and which indicates this position, is used.

For mean spherical candle-power, the following method is used, when the Matthews photometer is not available:

The lamp is placed in an adjustable holder and readings taken with the lamp in thirty-eight positions, as follows:

The measurement of the spherical intensity. For convenience the tip of the lamp and its base may be termed the north and south poles respectively

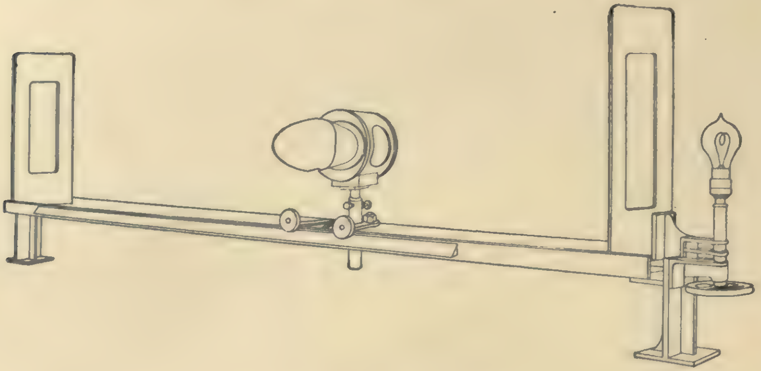


Fig. 80. Station Photometer.

The mean of 13 readings taken at intervals of 30°, is taken to give the mean horizontal candle-power.

Beginning again at 0° azimuth, thirteen readings are made in the prime meridian or vertical circle, the interval again being 30°, and the last reading checking the first.

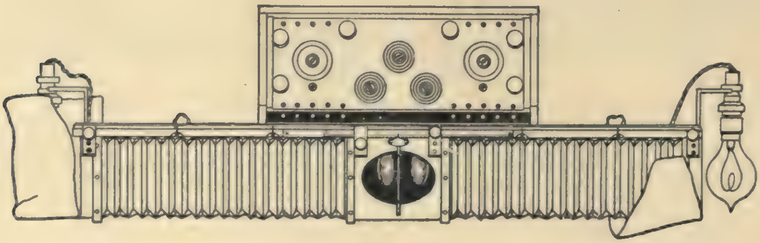


Fig. 81. Portable Photometer for Incandescent Lamps.

It will be noticed that four readings, two being check readings, have been made at 0° azimuth in each case. The mean of the four is taken as the *standard reading*, it being the value of the intensity, in this position, should the lamp be used as a standard.

Additional sets of thirteen readings each—the last reading checking the first one—are similarly made on each of the vertical circles through 45°, 90°, and 135° azimuth.

In combining the readings for the mean spherical intensity, a note is taken of the repetitions.

Neglecting the repetitions, which may also be omitted in part, in the practice of the method, there remain thirty-eight points, as follows:

	Distributed Values
The mean of four measurements at the north pole of the lamp	1
Four measurements on each of the vertical circles through 0° and 90° azimuth at vertical circle readings of 60°, 120°, 240°, and 300°	8
Four measurements on each of the vertical circles through 0°, 45°, 90°, and 135° azimuth at vertical circle readings of 30°, 150°, 210°, and 330°	16
Twelve measurements 30° apart at the equator	12
Four null values at the south pole of lamp	1
Total number of effective measurements	38

The points thus laid off on the reference sphere are approximately equidistant, being somewhat closer together at the equator than at the poles.

When the lamp is rotated, readings are taken for each 15° or 30° in inclination, from 0° to 90°, and from 0° to 270°. These are integrated values for their corresponding parallels of latitude on the unit sphere.

The mean spherical candle-power from these readings may best be obtained by plotting a distribution curve from the readings, determining the area of this closed curve by means of a planimeter and taking the radius of an equivalent circle as the value for the mean spherical candle-power.

The *Rousseau diagram* may be used for determining the mean spherical candle-power of a lamp when its vertical distribution curve is known. Fig. 82 shows such a diagram made up for a *gem lamp* with a bowl reflector. Where the horizontal distribution curve of the lamp is not uniform the values for the vertical distribution curve should be taken with the lamp rotating so as to give average values at each angle. One-half of the distribution curve is drawn to scale A and a circle B is drawn with the source of light O as a center. Radii C are drawn at equal angles about the light source and extended until they intersect the circle B. The points of intersection of these lines with the circle are projected upon the straight line $D\ E$. Distances from this line are laid off on the verticals F equal to the distances from the center of the circle to the points where the corresponding radii cut the distribution curve. The area enclosed between the straight line $D\ E$ and a curve drawn through the points just determined, $G\ H$, divided by the base line, is equal to the mean spherical candle-power of the lamp. If the mean candle-power of the lamp within a certain angle is desired, it is only necessary to find the area of the diagram within the space indicated by that angle and divide by the corresponding base.

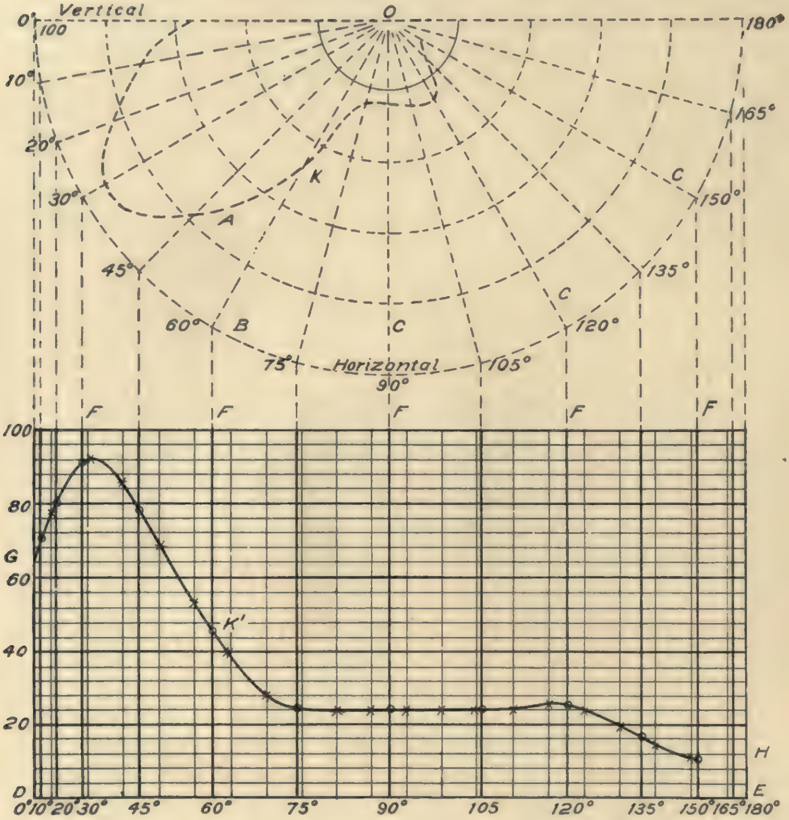


Fig. 82. Rousseau Diagram for Gem Lamp with Bowl Reflector.

In all tests the voltage of the lamp must be very closely regulated. A storage battery forms the ideal source of current for such purposes. In testing incandescent lamps, a standard similar to the lamp being tested is desirable and it should, preferably, be connected to the same leads. Any variation in the voltage of the mains then affects both lamps and the error introduced is slight.

ARC LIGHT PHOTOMETRY

Owing to the variation of the amount of light given out by an arc lamp in one direction at any time, due to variation of the qualities of the carbons, position of the arc, and also on account of the color of the light, etc., the photometry of arc lamps is much more difficult than that of incandescent lamps. The curves shown in Figs. 33 and 34 are average distribution curves taken from several lamps and will vary considerably for any one lamp. If the arc is enclosed, this variation is not so great.

The working standard should be an incandescent lamp run at a voltage above the normal so that the quality of the light will compare favorably with that of the arc. Since an incandescent lamp deteriorates rapidly when run at over voltage, the standard can be used only for short intervals and must be frequently checked.

Since an arc lamp can be mounted in one position only, mirrrors must be used to obtain distribution curves. A mirror is used mounted at 45° with the axis of the photometer, and arranged so as to reflect the arc when in different positions. A mirror absorbs a certain per cent of the light falling upon it and this percentage must be determined by using lamps previously standardized. The length of the photometer bar must include the distance from the mirror to the arc.

The Weber photometer is well adapted to arc-light measurements inasmuch as appropriate screens may be used to cut down the intensity of the light.

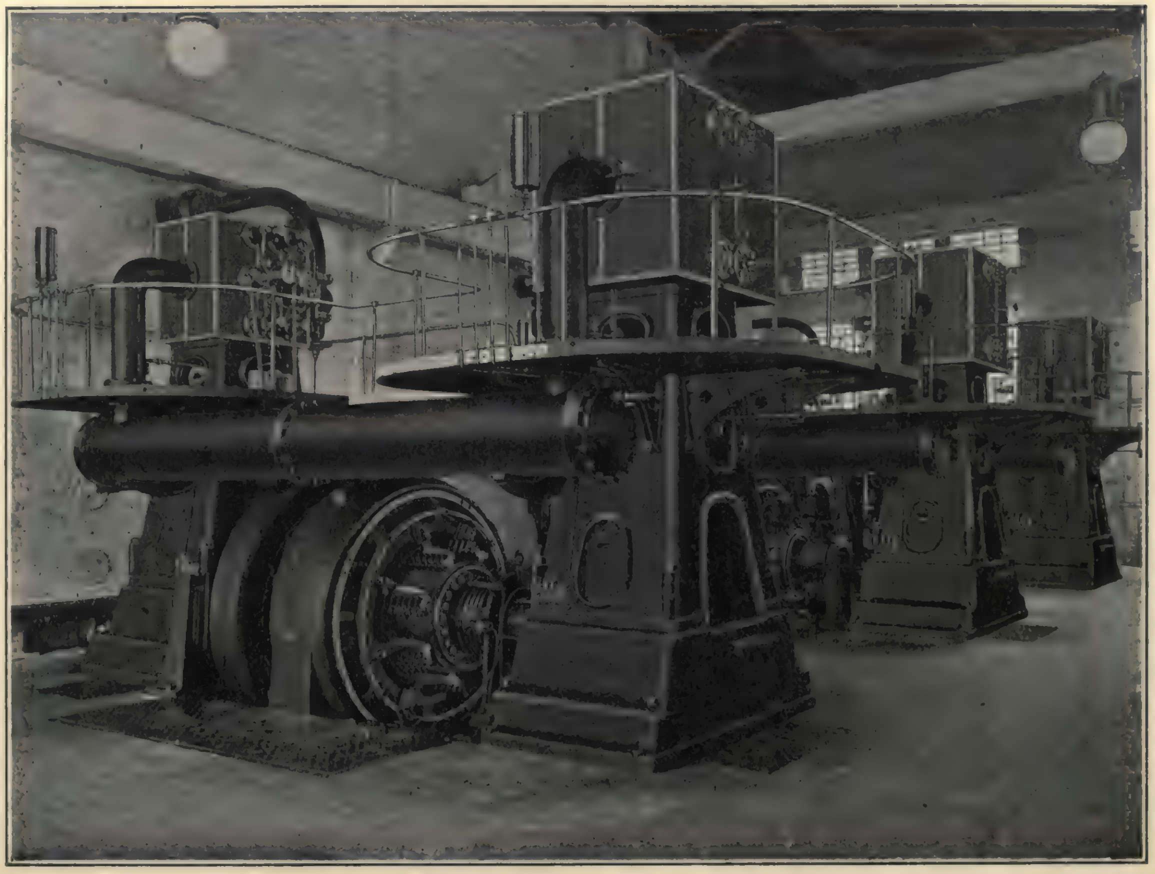
A special form of the Matthews photometer is also used for testing arc lamps.

For the comparison of the illumination from arc lamps as installed in service, an instrument known as an *illuminometer* is sometimes used. This consists of a light wooden box, readily portable, having a black interior and arranged with two openings. One of these openings is for the purpose of admitting light from the source being considered, to a printed card. The other opening is for the purpose of viewing this card when illuminated by the light source. The printing on the card is made up from type of different sizes, and the smallest size which is legible, together with the distance from the light source, is noted. Another method of application is to select some definite size of type and then to move the instrument from the light source to a point where this type is just legible and note the distance. From similar measurements taken on different lamps a good comparison may be obtained. Such an instrument is very convenient to use, and results obtained by different observers check very closely.

The *flicker photometer* is used for the comparison of different colored lights, the basis for comparison being that each light, though different in color, shall produce light sensations equally intense for the purpose of distinguishing outlines. It consists, in one form, of an arrangement by means of which a sectored disk is rotated in front of each light source, these disks being so arranged that the light from one source is cut off while the other falls on the screen, and *vice versâ*, any form of screen being used for making the comparison. The disks must be revolved at such a rate that the light, viewed from the opposite side will appear continuous. When the illumination of the two sides of the screen, under these conditions, is not the same, there will be a perceptible flicker and the screen should be so adjusted that this flicker disappears. The value of the light source can then be calculated from the screen reading in the usual manner. Another device consists of the use of a special lens mounted in front of a wedge-shaped screen, the lens being constructed so as to reverse the image of the two sides of the screen, as viewed by the eye, when such lens is in front of the screen. The lens is so mounted that it can be oscillated rapidly in front of the screen, giving the same result as would be obtained were it possible to reverse the screen at such a rapid rate as to cause the illumination on the two sides to appear continuous. The setting of this screen is accomplished as with the more simple forms.

Still another flicker photometer, the Simmance-Abady, makes use of a rotating wheel. This wheel is made of a white material having a diffusing surface, and its edge is so beveled that during part of a revolution a surface illuminated by one of the light sources is viewed through the eye-piece of the instrument, and during the other part of the revolution a surface viewed by the second light source is observed. The flicker occasioned by this change disappears when the screen is brought to a point where it is equally illuminated by the two light sources.

By the use of such forms of photometers it is found that results with different colored lights can be obtained, which are comparable with results obtained with lights of the same color.



WESTINGHOUSE 300 K.W. DIRECT CURRENT ENGINE TYPE THREE-WIRE GENERATORS.

Pittsburg, Cincinnati, Chicago and St. Louis Railroad, Columbus, Ohio.

ELECTRIC RAILWAYS.

PART I.

The general name "electric railway" is applied to all railways employing *electric motors* to supply power for the propulsion of cars. On all electric railways in commercial use to-day, the electric motor is used to furnish power to the driving wheels of the car or locomotive, the electric motor being the most efficient known means of transforming electrical into mechanical energy.

Electric railways are usually classified according to the methods by which current is supplied to the moving car. Thus, where an overhead trolley wire is used, as on the great majority of electric railways, the term *trolley road* is applied. Where an insulated steel rail is laid alongside the track rail for supplying current, as on the "elevated" roads in America and on a few interurban roads, the term *third-rail road* is used. Where, as on the street railways of a few large cities the conductors are placed in a conduit underneath the surface of the street, and current is taken by means of a plow or shoe running in the conduit, the name *electric-conduit railway* is most commonly applied. There are also a few systems using conductors buried beneath the pavement, and having contact buttons or sections of conductor rail on the street surface, which sections are supplied with current by automatic electromagnetic switching apparatus as the car passes, but which are normally dead and harmless. The overhead trolley and the third-rail systems are by far the most common.

A further general classification of electric railways has recently been made because of the introduction of alternating-current railway motors. The great majority of electric railways employ direct-current motors. Where alternating-current motors are used, the road is spoken of as one using single-phase alternating-current motors or three-phase alternating-current motors, as the case may be.

All electric railway systems in commercial use are operated on an approximately constant potential or voltage, and the various electric motor cars operating on the system are connected across the lines in parallel. The most common practice is to utilize the rails and ground as one side of the circuit, and the overhead trolley wire or "third rail" as the other side, as in Fig. 1. The trolley wire or third rail is, of course, thoroughly insulated from the ground. The positive poles of the generators at the power house are usually connected to the trolley wire, and the negative poles to the rails and ground. The various electric motor cars, being connected in parallel or multiple between the trolley wire and the ground, draw whatever current is necessary for their operation. Where the conduit system is used, both sides of the circuit are insulated from the ground, and the contact shoe or plow collects current from two conducting rails in the conduit, one of these conducting rails being positive and the other negative. A double-trolley system is also in use to a limited extent. In this system, both the positive and the negative sides of the circuit are insulated from the ground, one trolley wire being positive and the other negative.

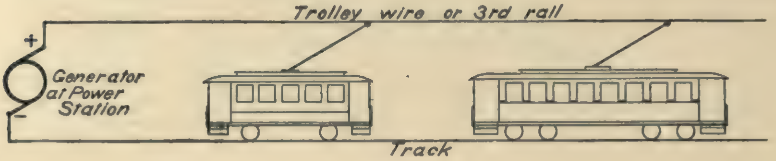


Fig. 1.

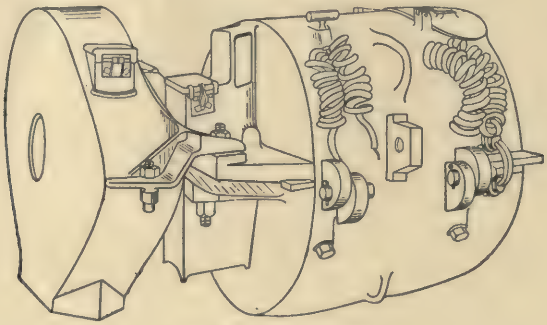
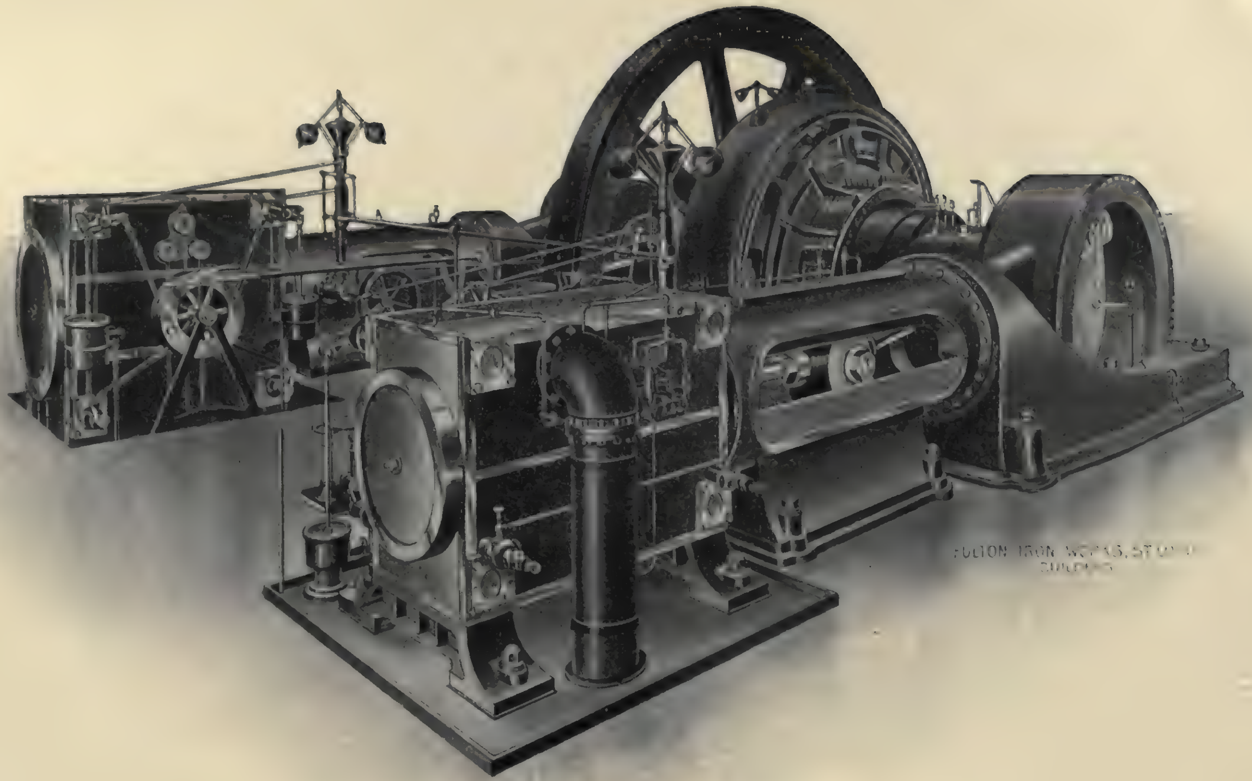


Fig. 2. Railway Motor.

Further discussion of the matters just outlined will be taken up in the succeeding pages.



HEAVY-DUTY CROSS-COMPOUND CONDENSING ENGINE, DIRECT CONNECTED TO 1,500 K.W. RAILWAY GENERATOR.

St. Louis Transit Company's Power House.
Fulton Iron Works.

CAR EQUIPMENT.

MOTORS.

The voltage most commonly employed by electric railways is 500 to 600; and the motors are 500-volt direct-current series-wound motors, designed especially for railway service. The electric railway motor must be dustproof and waterproof because of the position it occupies under the car. For this reason electric railway motors are made in the form of a steel case (Fig. 2), which entirely surrounds the field-magnet poles and takes the place of the yokes or frames that support the fields on stationary motors. Cast steel is the material now usually employed for railway motor cases and fields, on account of its mechanical strength and its high magnetic permeability. The four poles project inwardly from the case, as seen in the open motor case. Fig. 3, which is that of a Westinghouse No. 69 motor.

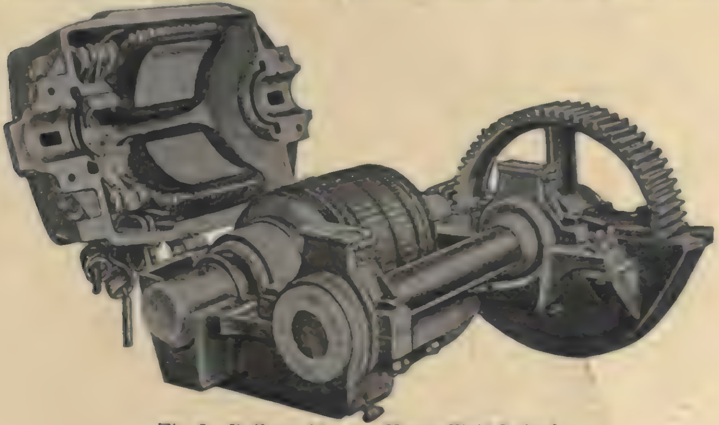


Fig. 3. Railway Motor. Upper Field Raised.

Railway motors have usually four poles because this permits of a symmetrical and economical arrangement of material around the armature, and hence permits the motor to be placed in the small space available on the car truck. Two-pole motors have been used in the past, but they were not as compact as the four-pole type

Characteristics of Railway Motors. The curve sheet, Fig. 4, for the Westinghouse No. 69 motor represents in general the characteristics of all direct-current railway motors.

The figures for each curve are found, with names corresponding to the curve to which they apply, at each side represented by vertical distance on the sheet. The amperes, represented by the horizontal distance, are marked at the bottom, and apply in common to all the curves.

The tractive effort at different current consumption is represented by a line curving upwards somewhat. This shows that the tractive effort increases, in a proportion greater than directly, as the current increases.

The torque required in starting may be many times greater than that necessary to maintain the car at full speed. The series-wound motor, therefore, furnishes this great starting torque more economically than a shunt-wound motor the torque of which is proportioned to the current. This feature of the series-wound motor makes it especially adapted to street railway work.

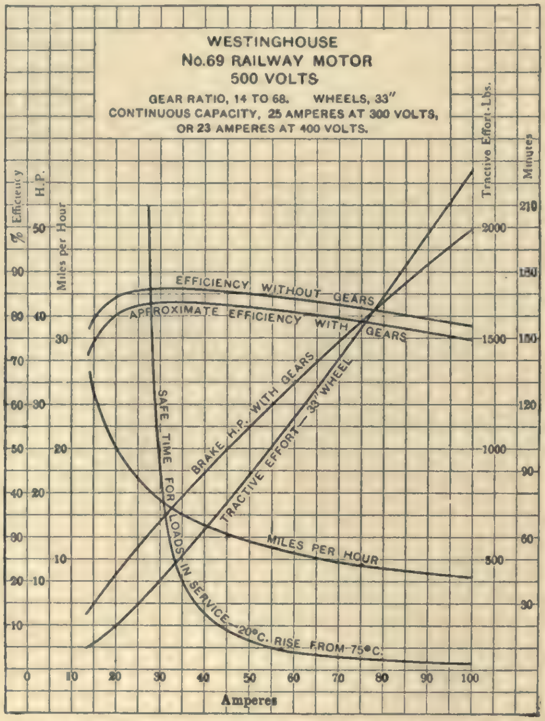


Fig. 4. Characteristic Curves of Railway Motor.

The efficiency curve shows the motor to have an efficiency of about 83 per cent with gears. Much other information may be obtained by a proper study of the curves.

The fields are worked near the point of magnetic saturation. This economizes metal and space and is also an advantage because of the fact that when so worked the armature reactions have very little effect on the fields. The neutral points between fields are consequently shifted very little and it is therefore not necessary to shift the brushes when the motor is reversed.

Armature Winding. The armature winding is what is commonly known as the series or wave winding, shown developed in the paper on Direct-Current Dynamos. This winding is shown in Fig. 5, which is an end view of an armature and commutator. In the figure, however, the armature is shown with a much smaller number of slots than a railway armature should have in practice. One reason for the employment of the wave or series winding on railway motor armatures, is that with this winding no cross-connections are necessary when only two brushes are used, and these two brushes may be placed 90° apart in a convenient and accessible position. Another reason is that the current, in flowing from one brush on the commutator to another, must always pass through the magnetic field of all four of the motor poles. This makes it impossible for any unbalancing of the magnetic circuit to cause more current to flow through one portion of the armature than is flowing through another portion. In a railway motor it has been found quite possible to have one pole or pair of poles exerting a greater magnetic attraction on the armature than another pair, owing to differences in the iron and differences in the clearance between the armature and pole pieces, which differences cause more magnetic lines of force to flow from some pole pieces than from others. With the lap-armature or the ring-armature winding, since the various portions of the armature under different poles are in parallel with one another, any difference in the magnetic flux between different poles will cause a different amount of current to flow in the various paths through the armature.

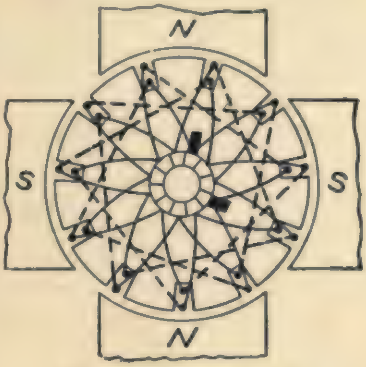


Fig. 5. Armature Winding.

General Data on Street Railway Motors.

Type of Motor.	Horse Power.	Amperes.	Speed Full Load.	Total Field Turns.	Slots.	Conductors per Slot.	Commutator Bars.	Weight complete with Gears.	Armature Complete.	Gears and Casing.	Commutator Bearing. Inches.		Pinion Bearing. Inches.		Diameter Armature.	Length.
General Electric 51	82	....	640	56	37	12	111	3875	953	338	3	5¾	3¼	8¼	16	10½
52	27	....	640	155.5	29	24	87	1725	357	265	2½	6⅜	2¾	7¾	11	9
57	52	....	470	110	33	18	99	2972	704	340	2⅞	6⅜	3¼	8¾	14	12
55	160	....	....	..	47	6	141	5415	1550	490	3¼	7½	3¾	11	....	..
67	40	....	....	110	37	18	111	2385	595	385	2⅝	6⅛	3	8	....	..
54	25	....	....	....	....	....	115	1831	395	285	2½	6	2¾	7¾	....	..
74	65	113	....	70.5	....	....	....	3534	845	415	3⅛	6¾	3⅝	8¾	....	..
Westinghouse 68	40	....	....	....	55	12	109	2280	505	330	2¾	6¾	3	7¾	14	8
69	30	....	....	....	35	....	105	1950	385	330	2¾	6	2¾	7	13	6¾
76	75	....	....	....	39	....	117	3840	505	860	3¼	8	3½	9	16½	..
56	55	....	....	....	39	....	117	3000	315	720	3	7½	3¼	8½	14	12
50 c	150	....	....	144	55	6	115	5550	1500	....	....	....	....	....		..
49	35	....	....	114	59	....	117	1925	438	327	2¾	6	2¾	7½	13⅞	6½

By reference to the winding diagram given in Fig. 5, it may be noted that a complete circuit through two coils ends at the segment adjacent to the one from which the start was made. It may also be noted in the table of motor data that all of the armatures have an odd number of segments and an odd number of slots. It is absolutely necessary in a wave winding to have an odd number of segments. Otherwise the winding could not be made symmetrical and the circuit through two coils be made to return to a segment adjacent to that from which the start was made. With equal spacing between the top and bottom leads of the two coils, an even number of segments would make the circuit return either on the segment from which the start was made or two segments from it.

The first drum-wound street railway motor armatures had as many slots in the armature as there were coils and segments. The great number of slots necessarily made the teeth very thin and consequently weak. This is very objectionable as sometimes the armature bearings wear away, allowing the face of the armature to drag on the pole pieces and thin teeth are bent out of shape.

Armatures are now almost entirely constructed with either two or three coils to a slot. When two coils are used in each slot with an odd number of slots an even number of coils results. If these were all connected to the commutator an even number of segments would be necessary. As this is not possible with a wave winding, one of the coils is "cut out." The ends are cut short and taped and it is termed a "dead" coil. This makes the winding somewhat unsymmetrical, all the coils not bearing the same angular relation to the commutator segments to which they are connected. This difference is, however, not great enough to affect the operation of the machine.

The Westinghouse 49 motor is an example of an armature with a dead coil. By reference to the table of motor data it will be seen that this armature has 59 slots. Two coils in each slot would make 118 coils. One of these, however, is cut out, giving 117 segments.

Cutting out a coil can be avoided by putting three coils in each slot.

An odd number of coils results then no matter what the number of slots may be. In the majority of examples given in the table there are three times as many segments as slots.

The sides of the slots of modern street railway armatures are straight. The coils are prevented from flying out by bands of wire extending over the tops of the coils around the armature. Steel or silicon bronze wire of about No. 14 gauge is used. Recesses are made in the armature teeth for the reception of these bands so that the wire when wound will come flush with the face of the armature. The bands are usually $\frac{3}{4}$ to $1\frac{1}{2}$ inches wide. The wires are well soldered together to secure them in place. One trouble experienced with armatures is the slipping off of these bands. The heated armature expands and stretches them. When the armature cools the bands are loose and then often slip off. When they do so the coils fly out by centrifugal force, strike the pole pieces and ground the motor.

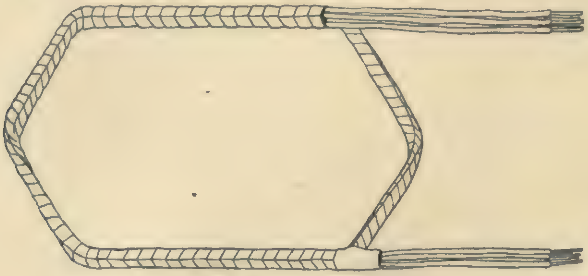


Fig. 6. Armature Coil.

Armature Coils. Railway motor armatures are to-day universally constructed with form-wound coils, which are wound on a form of proper shape and carefully insulated before being placed in the armature.

The coils of the smaller motors (those up to 40 or 50 horsepower) are usually wound with round wire. The cotton covering of the wire is depended upon for insulation. To strengthen this, however, the coils after being wound are immersed in an insulating compound and then baked in an oven. The whole coil is usually wrapped with insulating tape (See Fig. 6). The armatures of larger motors have coils made of copper bars. Mica is often placed between and around the bars for insulation, though oiled linen cloth tape cut bias is also employed, especially in repair work.

Field Coils. Field coils are so constructed that they may be readily removed should they become grounded or short-circuited.

Some makers wind them on a brass shell or form which is slipped over the pole piece. In some motors the field coils are composed of copper ribbon, wound bare, with ribbons of insulating material between the turns. Field coils of wire for the smaller motors, if not wound on shells, are wound on forms and before completion are taped in such a manner that they will hold their shape without being enclosed in a spool. The terminals are brought out where they will be of easy access when the field is in place (See Fig. 7).

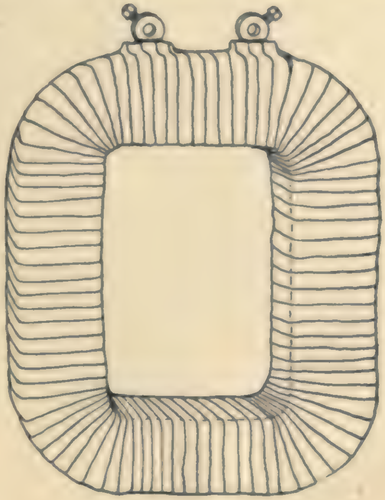


Fig. 7. Field Coil.

Armature Leads. In Fig. 3 is seen a completed armature in the motor casing of a Westinghouse No. 69 motor. Since the motors are four-pole, the two sides of any one coil occupy slots 90° apart in the armature coil, as indicated in Fig. 5. The ends of the coils are connected to commutator bars 180° apart. The relative position of the commutator connections of any armature coil can, of course, be varied so as to bring the brushes in the most convenient position in the motor casing. Brushes are always of carbon, and are placed where they can be easily reached from the opening in the motor casing over the commutator.

Motor Leads. The reversing of the current through the armature, independent of the field current, to secure reversal of direction of rotation of the armature, makes it necessary that four wires enter the motor. The portions of these wires connected permanently to the motor are termed the motor leads because they "lead out" the current. Sometimes an ordinary two-way connector is used in connecting these leads to the wires of the cable, but often a jack-knife connector is employed to facilitate connecting and disconnecting. Considerable difficulty has been experienced by the wearing away of the insulation of the leads where they rest on the motor shell. To avoid this there has recently come into use a lead protected by a spiral metal covering.

Brushes. That the motor may operate in either direction equally well, the carbon brushes are placed radially or nearly so. No provision is made for shifting their position relative to the fields. They usually occupy a position equidistant between pole tips. The common types are either ½ or ⅝-inch thick and from 2¼ to 4 inches wide.

Brush Holders. Two methods of securing the brush holders are employed. In Fig. 3, the brush holders may be seen to be secured in position by being bolted through the end of the motor shell. Fig. 8 shows the brushes mounted on a yoke which is secured to the motor shell. The yoke is of wood and provides the necessary insulation. Where the holders are fastened directly to the shell a block and washers of vulcabeston or other insulating material intervene to furnish the insulation between the shell and the holder. In practice the greatest difficulty experienced with brush holders is preventing them from becoming grounded by dirt and carbon dust which collects on the insulation.

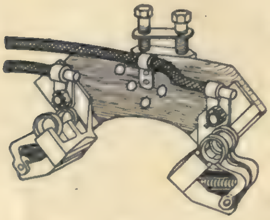


Fig. 8. Brush Holder.

Opening Cases for Inspection. Accessibility for inspection and repairs is essential in all railway motors. A lid is always provided directly over the commutator to facilitate inspection of the commutator and brushes. To open up the motor casing for more extensive inspection or repairs, three general schemes are employed. One is to have the lower half of the casing swing downward on a hinge as in Fig. 9, which illustrates the Westinghouse No. 38 B motor. The armature may be placed either in the lower half, as shown in Fig. 9, or in the upper half. When a motor of this type is to be opened the car is run over a pit, and the repair men work entirely from below.

Often the hinge pins are removed and the lower shell containing the armature is dropped down by means of a jack placed underneath.

Two handholes are usually provided in the bottom shell for observing the clearance between the armature and the pole pieces and also for removing dirt that may collect in the bottom of the shell.

Another scheme is to have motors open from the top, either by hinging the upper part of the motor casing, as in Fig. 3, or by having the top part of the casing lift off. Where this form of motor is used, the car body is hoisted clear of the truck, and the trucks are run out from under the car body before work is done on the motors. In this case, all the work can be done from above without the use of pits.

A third design is the box-frame motor casing, from which the armature can be removed endwise only. Such an arrangement is shown in Fig. 10, which is a view of a No. 66 motor of the General Electric Company. In this motor a sufficiently large opening is provided in the ends of the motor casing to permit of the armature being removed endwise. A plate or head, which accurately fits into this opening, carries the armature bearing. In removing armatures from motors of this kind, the usual method is to take the motor out of the trucks and stand it on end with the pinion up. The bolts being removed from the end plate, the armature can then be hoisted out of the case by means of a special hook attached to the pinion. Another plan that has been used in removing armatures from such motors, is to place the motor in an apparatus where the armature shaft can be held between centers, as in a large lathe. The motor

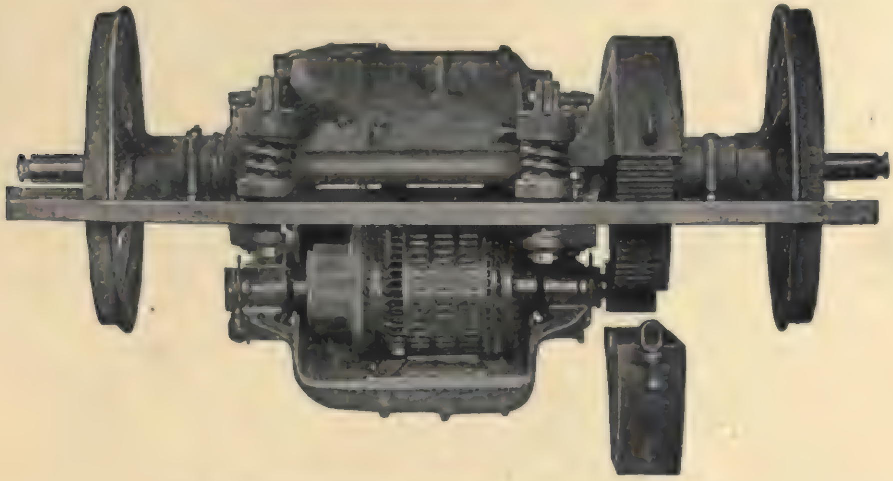


Fig. 9. Railway Motor. Lower Half of Casing Swung Down.

casing is then moved along in a direction parallel to the armature shaft, until the armature is exposed.

This latter box-frame type of motor is very compact; a stronger casing can be made for a given weight and space than if it were divided horizontally. Moreover, the magnetic circuit cannot be disturbed by imperfect contact between two parts of the casing. Where this type of motor is used, the bearings project inward under the commutator and armature, thus getting long bearings with a short motor, which is important where the room is limited, as, for example, in the case of a large motor mounted on a standard-gauge truck.

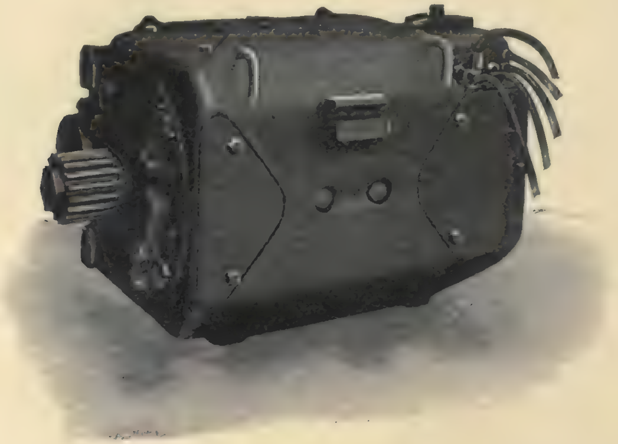


Fig. 10. Box-Frame Motor.

Gearing. In most cases, spur gearing is used to transmit power from the armature shaft to the car axle, although a few motors with armatures mounted directly on the car axle are in use. Various gearings other than the simple spur gear have been tried, such as worm gears, chain and bevel gears. Practically all have been abandoned in favor of the single-reduction spur gearing, which is the most satisfactory from the standpoint of wear and efficiency. This gearing is shown in Figs. 3 and 9. The gearing is covered with a gear case (Fig. 9), which is usually of steel, though gear cases of thin sheet metal and wood are sometimes used. A solid gear is shown in Fig. 11, and a split gear in Fig. 12.

The gear ratios in common use vary from 5 to 1 to 2 to 1, the larger ratio being common on the smaller motors. A ratio often used on motors of 30 to 50 horsepower is 4.78 to 1, the gear having 67 teeth, the pinion 14 teeth.

Street car wheels are usually 33 inches in diameter. This makes necessary 612 revolutions per mile. With a gear ratio of 4.78 the armature revolves 2,925 times per mile. At 15 miles per hour, this gives 731 r.p.m.

Lubrication. The lubrication of railway motors was for a number of years carried on almost exclusively with grease, which it was customary to place in the gear casing and in grease boxes over the armature and car-axle bearings. Grease becomes most efficient as a lubricant only when the bearing is heated sufficiently to make the grease run like oil. Oil is now being used to a considerable extent, especially for larger motors. It is fed to the bearings by various devices that allow a very slow feed, such as wicks and lubricators adjusted to pass a small amount of oil per hour.

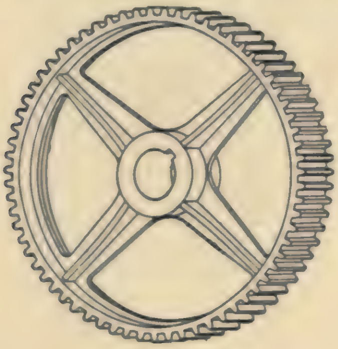


Fig. 11. Solid Gear.

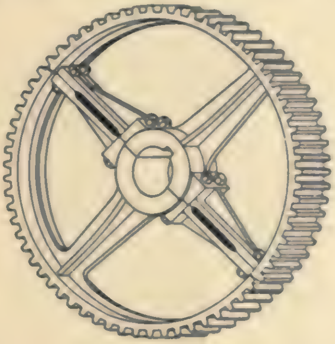


Fig. 12. Split Gear.

Bearings. Railway motor bearings are usually of Babbitt metal, which metal is cast into a steel shell. This shell fits into receptacles in the motor casing, which can be seen in Figs. 3 and 9. A steel shell is used so that the worn-out bearings can be easily renewed and the shells taken to a Babbitt melting furnace to have new Babbitt poured into them.

The motor has two sets of bearings, those for the armature and those for the axle upon which the motor is mounted. The axle bearings are always split diametrically to avoid removing a wheel when a bearing is replaced. On the later designs of motors these are of brass, no Babbitt metal being used. The armature bearings are distinguished by the terms "gear end" and "commutator end" bearings. The gear end bearing is usually of larger diameter and of greater length because of the thrust of the gears it must take in addition to the weight of the armature. This bearing is split so that it may be removed and replaced without the removal of the gear. The commutator end bearing is in one piece. Armature bearings are shown in Fig. 13.

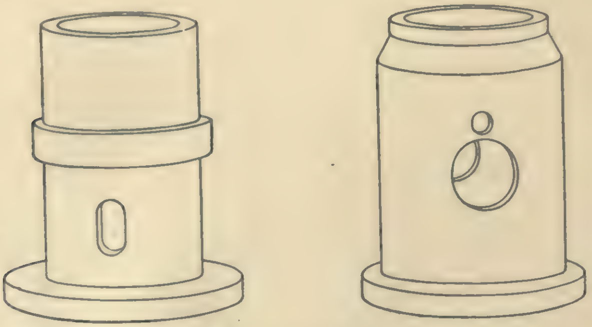


Fig. 13. Armature Bearings.

Motor Suspension. Two methods of suspending motors flexibly on trucks are in common use. That end of the motor which has bearings on the car axle cannot, of course, be flexibly suspended with regard to the axle; but the other end of the motor can be placed on springs, or rest on a bar supported on springs, as shown in Fig. 14. This suspension is commonly called *nose suspension*. Instead of having a special bar and special springs for the nose of the motor, the nose may rest upon some part of the truck that is carried upon springs. Thus, on the M. C. B. type of swivel truck, the nose usually rests on the truck bolster, and thus gets the benefit both of the bolster springs and of the equalizer springs of the truck. Another general plan of suspension is that known in one form as *cradle suspension*, and in another form as *side-bar suspension*. A side-bar suspension is shown in Fig. 15. Here a larger percentage of the weight of the motor is evidently taken by the springs than in the case of nose suspension. It is desirable to relieve the car axle of as much dead weight as possible. By dead weight is meant weight resting upon it without the intervention of springs.

Motors of the New York Central Electric Locomotive. These motors are a radical departure from the usual type of railway motors. The locomotive on which they are mounted has four driving axles, upon each of which is mounted an armature, direct, no gears being used, Figs. 16 and 17. The motors are remarkable for three special features: The method of mounting the armature, the shape of the pole pieces, and the path of the magnetic flux.

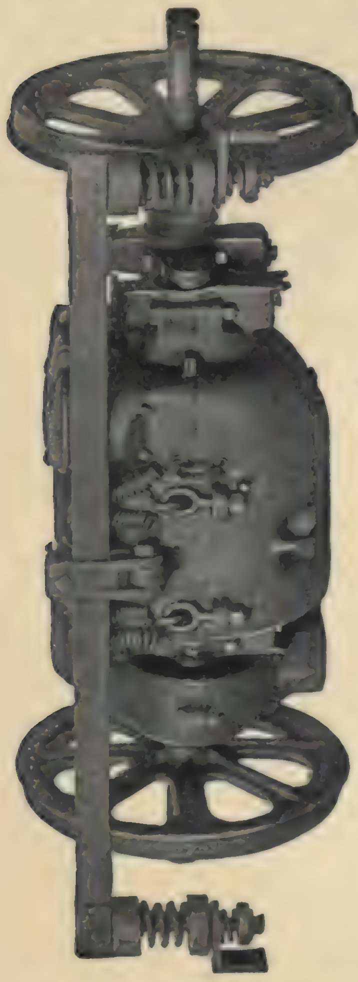


Fig. 14.—Nose Suspension.

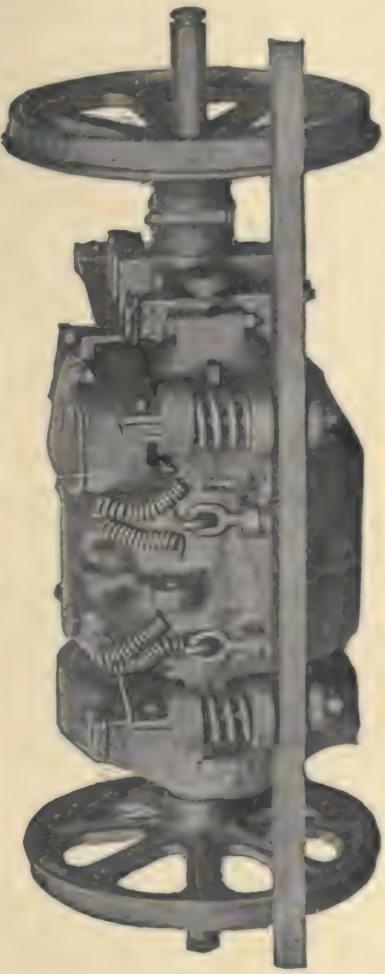


Fig. 15. Side-bar Suspension.

The mounting of the armature upon the driving axle and the motor fields on the truck frame makes it necessary to have flat pole pieces in order that the armature may play up and down as the journal box and axle slide in the guides of the truck frame. The shape of the pole pieces may be observed in the drawing Fig. 16. When in the central position there is a $\frac{3}{4}$-inch air gap between the armature and pole pieces. The magnetic flux is continuous through the fields of all four of the motors. It returns through the cast steel side frames of the truck and two bars placed in the path.

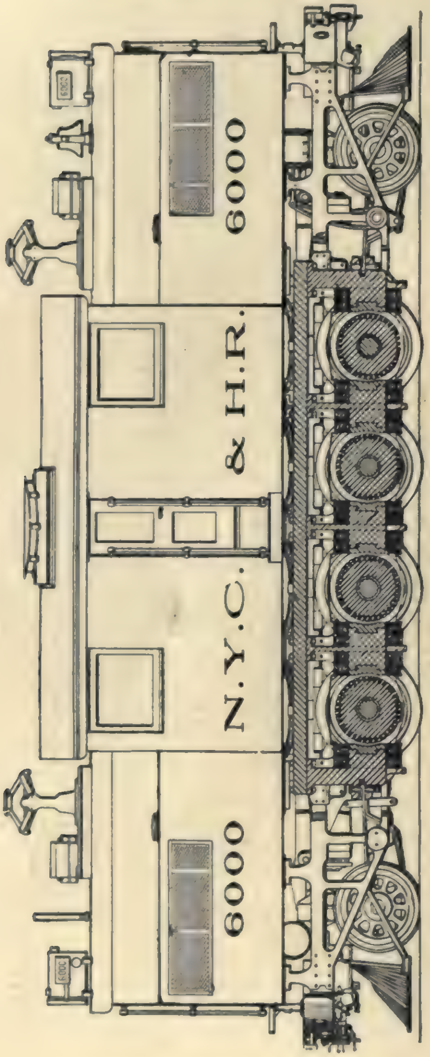
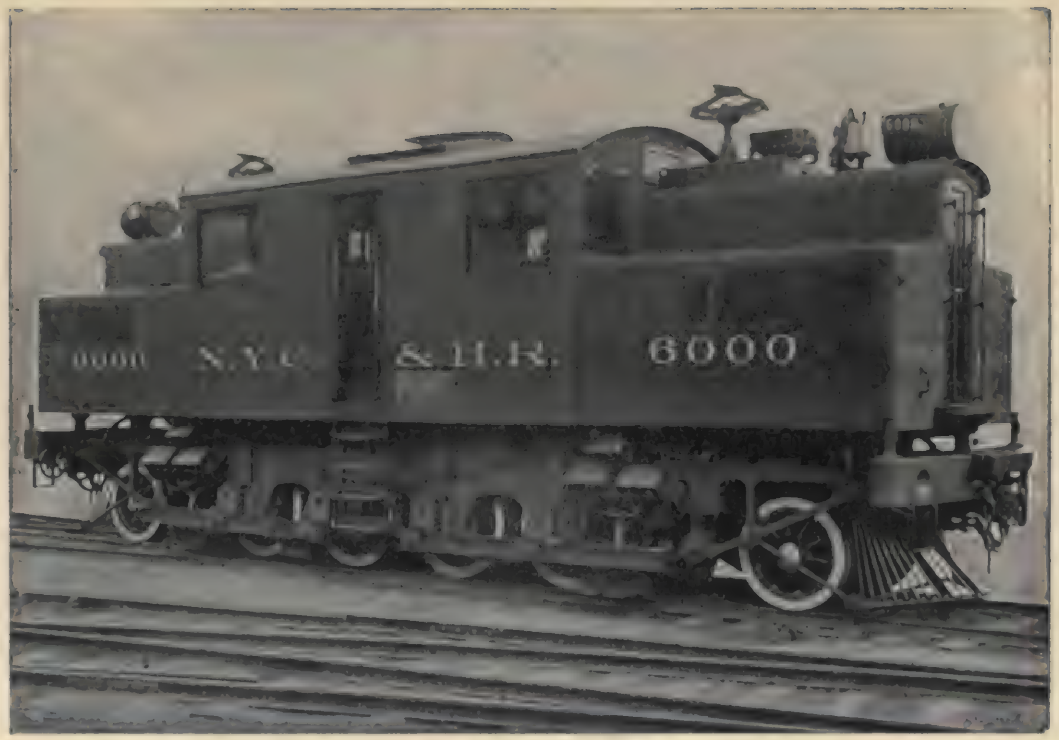


Fig. 16. Longitudinal Section of New York Central Locomotive.

The brush holders are so mounted that the brushes occupy a fixed position relative to the armature. The armature is removed by lowering it with the wheels and axle upon which it is mounted. This can be done without disturbing the fields of the motor.

CONTROLLERS.

In an ordinary electric car, current is taken from the wire through the trolley wheel and pole, and is first led from the trolley base through overhead switches or a circuit breaker, and then to the controller, from which it passes through the motors and



95 TON ELECTRIC LOCOMOTIVE FOR NEW YORK CENTRAL RAILROAD.

General Electric Company.

thence through the motor frames, car truck, and wheels to the rails and ground. If the car is designed to be operated from either end, an overhead switch or circuit breaker is placed over each platform of the car so that current can instantly be cut off entirely from the controllers by throwing the switch or circuit breaker at either end of the car.

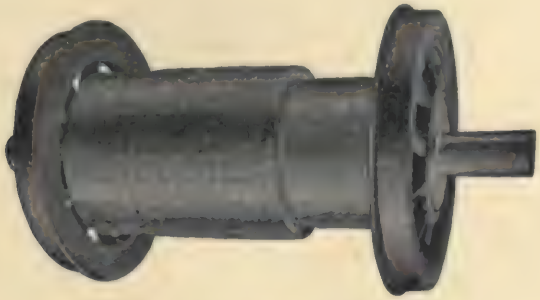


Fig. 17. Armature Axle and Wheels.

The lighting circuit is run from the trolley base independently of the motor circuit, and has its own switch and fuse box. Current for the lights is taken from the trolley circuit before it reaches the main switches or circuit breakers. Current for electric heaters, if such are used, is likewise taken from a separate circuit. On a 500-volt system five 100-volt lamps are usually connected in series for car lighting. As many multiples of five can be employed as are necessary to light the car.

Rheostat Control. The simplest form of controller is that employed where only one motor is used on a car. A rheostat is placed in series with the motor when started, just as on a stationary motor; and the function of the controller is to short-circuit this resistance gradually until it is entirely cut out and the motor operates with the full voltage. The controller also has a reversing switch by means of which the relative connections of the armature and fields are reversed, which, of course, changes the direction of rotation of the motor armature. Such a simple equipment as this, however, is rarely to be found in practice.

Series-Parallel Control. Single-truck cars usually have two motors, one on each axle; and on such cars a series-parallel controller is the kind usually employed. Diagrams of connections on the various points of a series-parallel controller (Type K 6) of the General Electric Company, are given in Fig. 18.

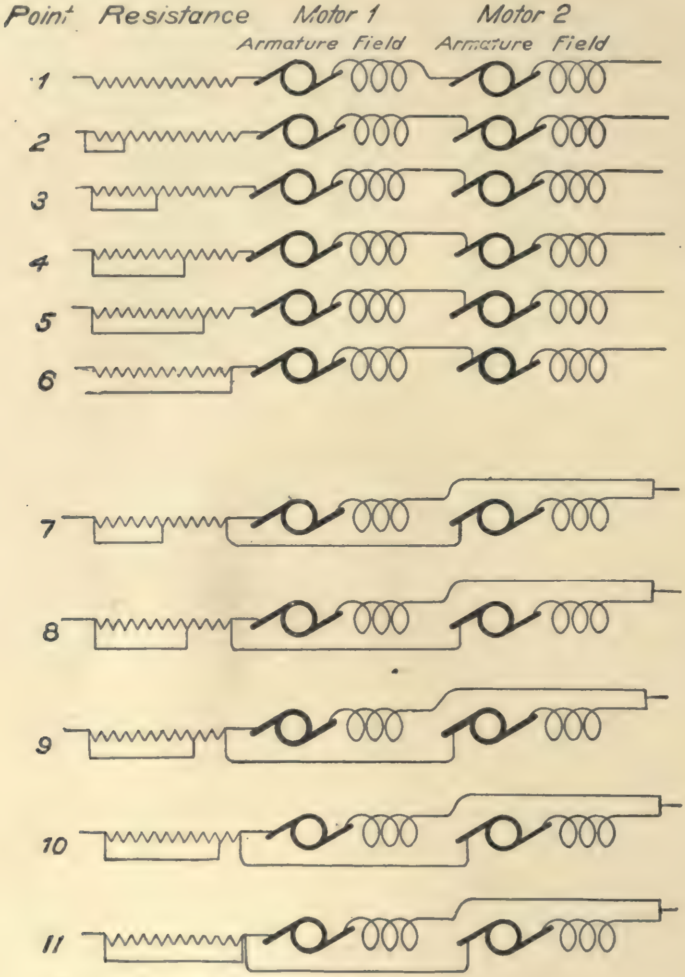


Fig. 18. Diagram of K6 Controller Combinations.

From these diagrams it is seen that the motors are first operated in series until all the resistance is short-circuited by the controller. When this has occurred, the cars are running at about half speed. The next point on the controller puts the two motors in multiple, with some resistance in the circuit, which resistance is cut out upon the following points, until at full speed the two motors are in multiple, without any resistance in the circuit.

Four Motors. Where four motors are used on a car, as is frequently the case with double-truck cars, the motors on each truck are usually controlled just as in case of the two-motor equipment that has been described; but each pair of motors is operated in multiple. That is, on the first points of the controller, the two motors of a pair are in series, as in Fig. 19, and the two pairs are in parallel; and on the last points of the controller, all the motors are in parallel, as in Fig. 20.

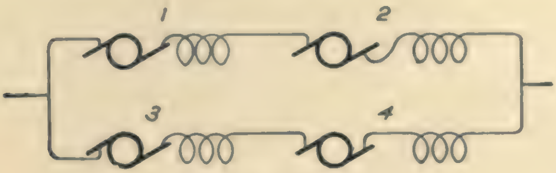


Fig. 19. Motor in Series.

Controller Construction. The controller (Type K) shown open in Fig. 21, which in its various forms is the type most commonly used on street cars in the United States, has a contact cylinder or drum mounted upon the main shaft of the controller. This contact drum carries contact rings insulated from the drum, and is suitably interconnected, as indicated in Fig. 22, which shows the contact rings of the controller as they would appear if rolled out flat. Contact fingers are placed along the left side of the controller, as seen in Fig. 21, one for each ring on the drum; and as the controller handle is turned to revolve this drum, the contact fingers make contact with the rings on the drum and give the various connections. Alongside the main controller drum is a reverse drum which simply reverses the armature connections of the two motors.

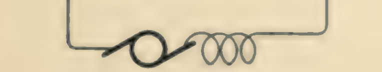


Fig. 20. Motor in Parallel.

Controller Wiring. The connection between motors, controllers, and resistances, with two motors and a K 6 controller is shown in Fig. 22. A careful study of this will show the combinations to be the same as indicated in the diagram, Fig. 18. The wiring is rather complicated; and in practice, to avoid confusion, the ends of each wire are labeled with tags showing the terminals to which they belong.

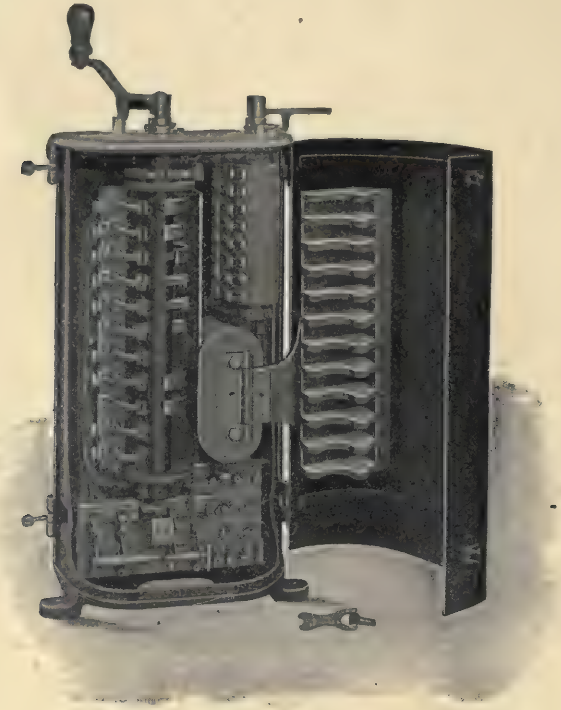


Fig. 21. Controller.

With the aid of Figs. 22, 23 and 24, the wiring of a type K 6 controller with two motors may be followed. Figs. 23 and 24 are for a different controller but can be used to assist in an understanding of the complicated diagram 22. The current leaves the choke or kicking coil of the lightning arrester and passes through the blow out coil of the controller. It then goes to the top finger T of the controller. On the first point the circuit is as shown in Fig. 23. The top segment A makes contact with the top or trolley finger.

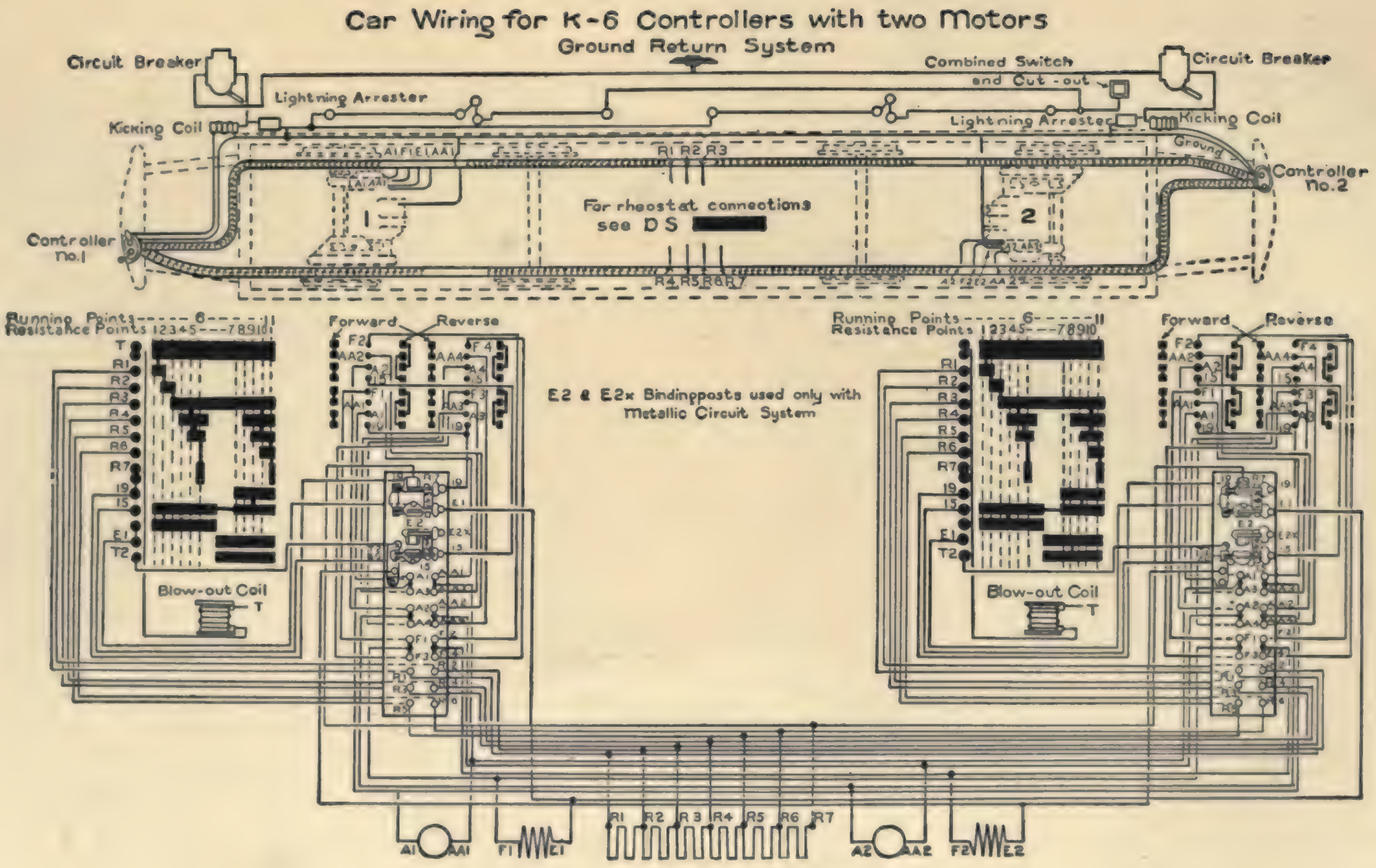

Car Wiring for K-6 Controllers with two Motors
Ground Return System
Circuit Breaker
Lightning Arrester
Kicking Coil
Combined Switch and Cut-out
Circuit Breaker
Lightning Arrester
Kicking Coil
Ground
Controller No.1
Controller No.2
A1 F1 E1 AA1
R1 R2 R3
R4 R5 R6 R7
1
2
For rheostat connections see DS
Running Points ----- 6 ----- 11
Resistance Points 12345---78910
T
R1
R2
R3
R4
R5
R6
R7
19
15
E1
T2
Blow-out Coil
T
Forward
Reverse
F2
AA2
A2
15
F1
AA1
A1
19
AA4
F4
A4
F3
AA3
A3
E2 & E2x Bindingposts used only with Metallic Circuit System
A1
AA1
F1
E1
R1
R2
R3
R4
R5
R6
R7
A2
AA2
F2
E2

Fig. 22

All but the lower five segments of the cylinder are electrically connected together by means of the iron cylinder upon which they are mounted. On the first point then the current passes from the cylinder over R_1, and with straight series connections of the resistances, it goes through all of the rheostats under the car, and returns to the controller over the last resistance lead, R_7. Behind the motor cut-out switches at the base of the controller this lead is tapped into a wire one end of which leads to finger 19 of the controller, and the other end through the cut-out switch and reverse cylinder to No. 1 armature. The current takes the latter path, passes through the armature of the motor and returns by way of the reverse cylinder, thence through the fields of No. 1 motor and then through the cut-out switch of No. 1 motor and to finger E_1, of the controller. Segments O, M, N and L, shown in Fig. 23, and corresponding segments of Figs. 22 and 24, are insulated from the remainder of the controller cylinder. From finger E_1 and segment O (Fig. 23) the current passes over finger 15 through No. 2 cut-out switch and the reverse cylinder to the armature of No. 2 motor. Returning it passes through the reverse cylinder, then back through the fields of No. 2 motor and to the

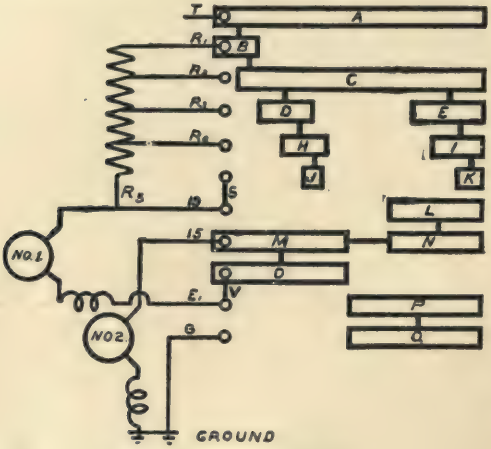


Fig. 23. Motors in Series.

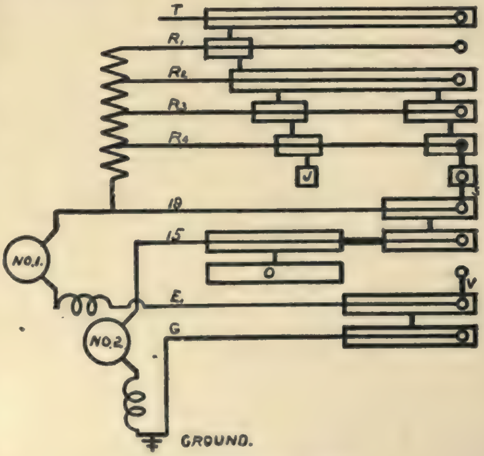


Fig. 24. Motors in Parallel.

ground, which is usually through a connection on the motor casing.

On points 2, 3, 4 and 5, the successive series points of the controller R_1, R_2, etc., make contact with segments B, C, etc., Figs. 23 and 24, until finally finger 19 rests on segments J, the resistance is all cut out and the motors are connected in series directly across the line. A further movement of the controller handle changes the motors from series to multiple connection and inserts in the circuit a portion of the external resistance. There are four separate stages in making this change. First, the resistance fingers slide off their segments and the resistance is inserted in the line. Second, fingers E_1 and G make contact with segments P and Q. Motor No. 1 is then across the line in series with the resistance; the circuit being from E_1 to ground over G. When the lower finger E_1 makes contact with P, the upper one has not yet left segment O. This short-circuits No. 2 motor, the path being from the ground, up wire G, thence by way of segments P and Q and through connecting clip V, between the two E_1 fingers back through finger 15 to the motor.

A further movement of the controller handle causes the fingers to leave segments M and O and No. 2 motor is open-circuited until finger 15 makes contact with segment N. When this takes place the motors are in multiple. On the successive points after this the external resistance is cut out in the same manner as previously described.

By reference to Fig. 22, it will be noticed that the leads to the motors and the resistances are tapped on wires of the cables connecting the two controllers on the ends of the car. The two ends of these wires, with the exception of the armature wires, lead to similar binding posts on the two controllers. The armature wires are interchanged connecting at one controller into binding post A A, while the other end connects into binding post A. This change of connection is necessary in order that the reverse handles be forward for forward direction of movement of the car.

To reverse a series motor it is simply necessary to reverse the direction of flow of the current in either the armature or field. For several reasons, it is advantageous in the case of the street railway motor to reverse the current in the armature rather than in the field. Figs. 25 and 26 show how this is accomplished. The squares shown in the figures represent the lugs on the reverse cylinder as shown in Fig. 21. With the reverse handle in one position (Fig. 25), the large lugs are under the reverse fingers, and current passes from finger 19 to finger A_1, and from finger 15 to finger A_2. Fig. 26 shows the relative position of reverse fingers and lugs for the reverse position of the controller handle. In this case the current passes from finger 19 to A A_1, and from finger 15 to finger A A_2. The effect is to change the direction of flow in the armatures while that in the fields remains the same as may be observed by the arrows.

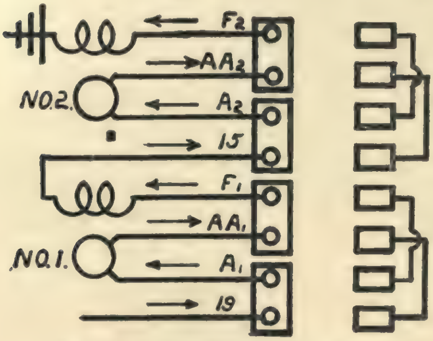


Fig. 25. Forward Position of Reverse.

Wiring of Type L Controllers. The type L controller, shown in Fig. 27, while accomplishing the same results as the type K, is wired in a radically different manner. The circuit is opened in changing from series to multiple connections. The controller handle makes two complete revolutions in moving from the series to the multiple position. It is geared to the rheostatic cylinder in such a manner that the first half of both the first and second revolutions gives this cylinder one complete turn. During the second half of the revolution the cylinder is returned to its original position. The controller handle is so connected to the commutating arm that this stands in a central position for the off position of the handle. At the beginning of the first revolution it is swung to the left, throwing the motors in series. At the beginning of the second revolution it is moved to the right, putting the motors in multiple.

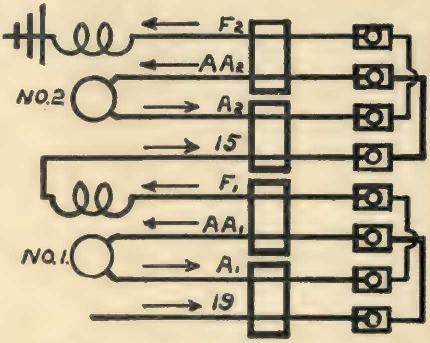


Fig. 26. Reverse Position of Reverse.

The rheostats instead of being wired in series are connected in multiple. Current passes from the blow-out coil to the bottom fingers of the controller S, and thence to the rheostats. On the

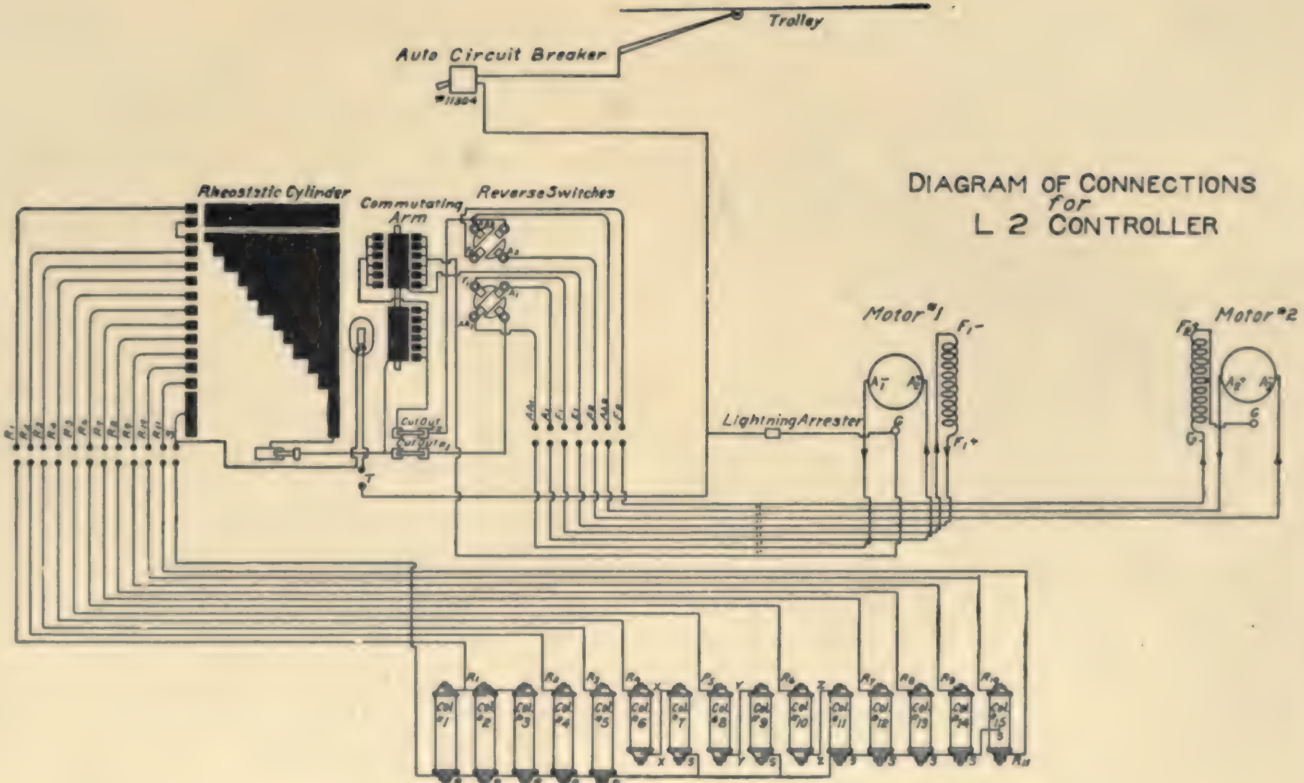


DIAGRAM OF CONNECTIONS
for
L 2 CONTROLLER
Trolley
Auto Circuit Breaker
#11804
Rheostatic Cylinder
Commutating Arm
Reverse Switches
Cut Out
Motor #1
Motor #2
F_1-
F_1+
F_2
A_1
A_2
G
Lightning Arrester
T
Col #1
Col #2
Col #3
Col #4
Col #5
Col #6
Col #7
Col #8
Col #9
Col #10
Col #11
Col #12
Col #13
Col #14
Col #15
X
Y
Z
S

Fig. 27.

first point the current returns over R_1 to the controller cylinder. It passes off through a collar at the base of the cylinder through No. 1 cut-out, and the reverse, which is shown in the central position, to No. 1 motor. On returning to the controller over E_1 it passes to the upper section of the commutating arm. In the diagram this is shown in the central position. In series it is thrown to the left. The current then passes from the commutating arm to No. 2 cut-out, and to No. 2 motor. Movement of the controller handle further multiplies the paths through the rheostats and finally, when fingers S rest on the cylinder, the rheostats are short-circuited. If the controller handle is moved still farther, the rheostat cylinder is returned to the off position and the commutating arm is thrown to the left. With the arm in this position the current divides, one portion passing to No. 1 motor as before and to ground by way of the upper section of the commutating arm; while the other branch goes by way of the lower section of the commutating arm to the cut-out switch for No. 2 motor and thence to the motor.

Reversing is accomplished by one-quarter revolutions to the right and left of the segments shown. It is evident that this will connect either A_1 or A A_1, to the trolley. And likewise connect the other armature leads.

Reversal. The reversing handle and the main controller handle are made interlocking so that the motors cannot be reversed without first throwing the controller to off position. This is to prevent damage to the motors through careless or inadvertent throwing of the reverse handle when the controller is on some of its higher points. Such a reversal would cause an enormous current to flow through the motors, and would be likely to damage them and to open all the circuit breakers and fuses in that circuit. The reason for the enormous flow of current is, of course, that the counter-electromotive force of the motors, when reversed with the car going at some speed, would materially add to the electromotive force of the trolley line, instead of opposing it as when the cars are in operation. The current flowing through the motor circuit would then be equal to (*electromotive force of line* + *electromotive force of motors*) ÷ (*resistance of motors*), which would result in a very large current.

Magnetic Blow-Out. On the Type K controller as well as on most other successful controllers, the flashing or arcing between contact rings and fingers, which occurs when the circuit is broken, is materially reduced by a magnet that produces what is called the magnetic blow-out to extinguish the arc. This magnet derives its current from the main circuit, and is so arranged as to create a strong magnetic field in the neighborhood of the place where the arc is formed Fig. 21 shows a Type K controller open with the magnetic blow-out magnet thrown back on a hinge. The coil which produces this magnet is seen in the right side of the controller. The main contact drum is in the middle, and the reversing drum at the right hand. There are in use a number of other controllers built upon these same general principles but differing in mechanical arrangement.

Controller Notches. All controllers are provided with some device which prevents the motorman from stopping the controller handle between the various points or notches, as the stopping between points might result in drawing an arc or an imperfect contact. The most common arrangement to prevent this is a notched wheel on the controller shaft, against which bears a small wheel of just the right size to enter the notches. The small wheel is held against the notched wheel by a strong spring. As the tendency of the small wheel is to seek the bottom of the notches, it is difficult to stop the controller handle anywhere between notches, and the motorman is thus given a guide which tells him without any effort on his part just where the notches are.

To prevent advancing the controller handle too rapidly and avoid the jerking of passengers, excessive currents and slipping of wheels during acceleration, several devices have been planned. On the multiple unit control systems, a limit switch is usually provided which prevents the controller advancing when the current exceeds a predetermined amount. A device to accomplish the same results on the K type of controllers is termed the Automotoneer. A cam connected with a dash pot prevents movement of the controller handle to the successive notches faster than a previously prescribed rate.

A switch is usually provided in a controller, for cutting out of service one motor or a pair of motors if defective, and allowing the car to proceed with the good motor or motors.

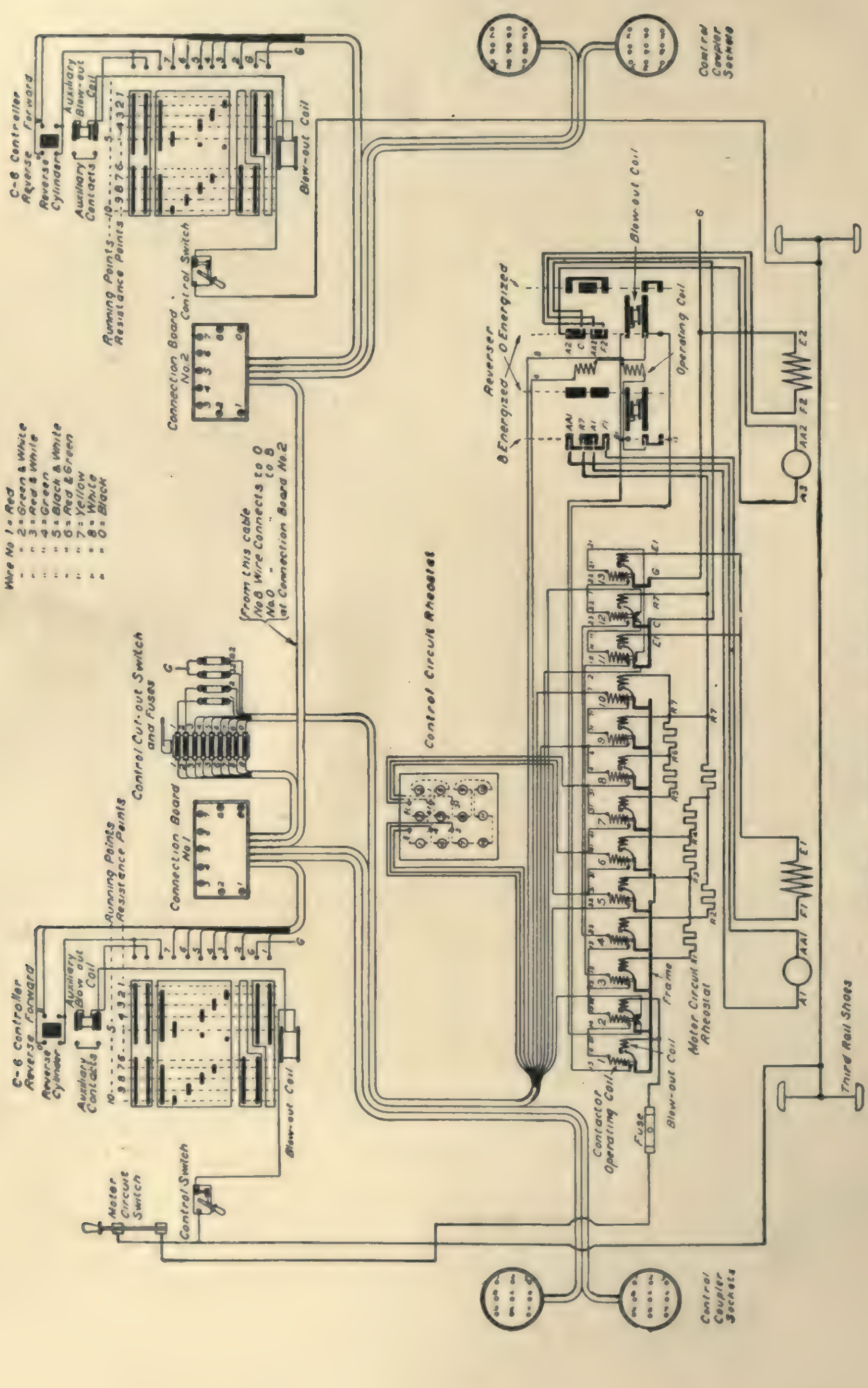
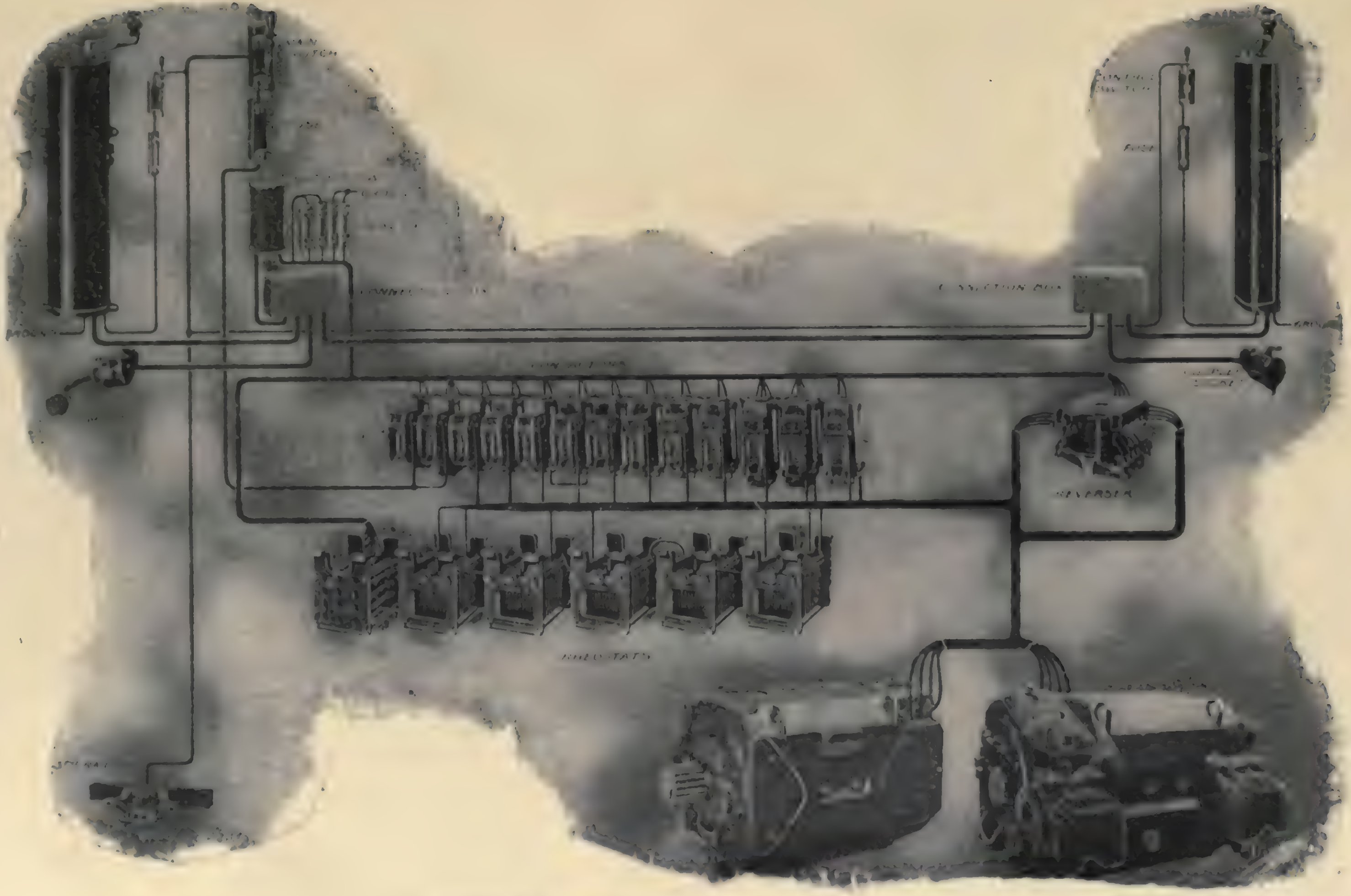


Fig. 28a. Car Wiring for G. E. Train Control System.



TYPE M RAILWAY MOTOR CONTROL SYSTEM.

General Electric Company.

MULTIPLE-UNIT CONTROL.

A system called "multiple-unit control" or "train control" has come into use where it is desired to operate motors under a number of different cars in a train; all the motors being controlled from the head of the train or from any other point on the train where the motorman may be stationed.

There are several types of multiple-unit control. In all of them there is on each car a controller of some kind which controls the current flowing to the motors on that car. This controller is operated from a distance by means of electro-magnetic or electro-pneumatic devices controlled by circuits called *pilot circuits*, which circuits are connected to the motorman's controller. All the pilot circuits of a train are connected together by means of train plugs which make the connections between the cars. The pilot circuits of each car are connected to a motorman's controller on that car and this makes it possible to operate the train from any controller.

Sprague Multiple-Unit System. In the earliest form of multiple-unit control—which was that devised by F. J. Sprague—the motors on each car were controlled by an ordinary Type K controller, which had geared to its shaft a small pilot motor. The pilot motor was controlled by the pilot circuits connected with the motorman's controller.

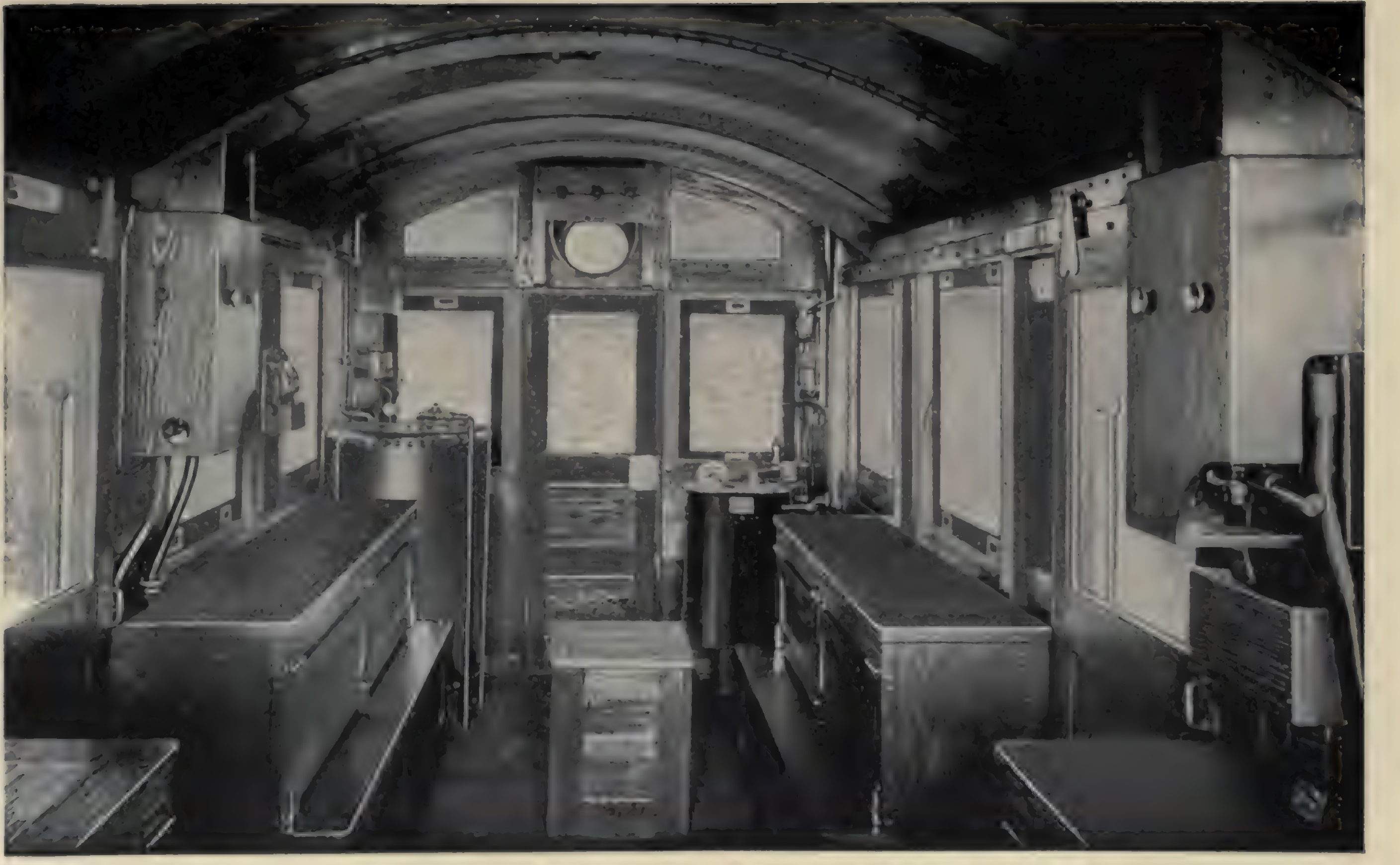
In the more recent forms of multiple-unit control, the use of main controllers having contact cylinders has been practically abandoned. The contacts are made instead by a number of electro-magnetic or electro-pneumatic contact devices sometimes called *contactors.*

General Electric Train Control. In the General Electric train-control system each contact for the motor circuits is made by a solenoid magnet which draws together two heavy copper contact fingers to establish the circuit. A magnetic blow-out coil in series with the contact is also provided. The contactors make contact only when energized by a small amount of current from the master or motorman's controller. In Fig. 28*a* is a diagram of the car wiring for a motor car equipped with this system. The motorman's controller is a drum controller, but is comparatively small since it has to handle only the small amount of current necessary to operate the solenoid magnets of the contactors. It is evident that by connecting together the pilot circuits, which are connected to the motorman's controller, so that the pilot circuits will be continuous for the entire length of the train, any number of cars equipped with the train-control system can be operated; and similar contacts will be made by the contactors under all the cars simultaneously, by virtue of the circuits established by the master controller at any platform.

Besides controlling the contactors, the master or motorman's controller must control an electro-magnetic reversing switch, or *reverser,* to change the direction of car travel.

The handle of the motorman's controller is provided with a push button, which must be depressed while the current is turned on. Should the motorman release this push, the circuit through the controller will be opened and all the contactors will fall open. This handle is called the *dead man's handle* because it is put there to provide for cutting off the current should the motorman fall dead or in a faint at his post.

The flow of the current in the control circuits, which operates the reverser and picks up the contactors on the several points may be followed in the diagram Fig. 28*a*. With the reverse handle in the forward position and the controller on the first point, current passes from the main circuit through a single-pole fused switch called the control switch and through the auxiliary blow-out coil to a finger bearing on the upper section of the master controller cylinder by which connection is established to the adjacent finger and thence to the reverse cylinder. It leaves this over wire No. 8, passing by way of the connection board and control cut-out switch to the forward operating coil of the reverser, thence through the forward blow-out coil and over wire 81, through the switch underneath contactor No. 2 and to ground G, by way of wire B 2 after passing through the fuse shown. The current through the operating coil of the reverser, having thrown this, the path is changed somewhat. The current then instead of passing from the reverser over wire 81, is conducted through wire 15, through the operating coils of contactors No. 1, 2, 3, and 11 in series, through the switch under contactor No. 12, and to ground through finger 1 of the controller. Contactors 1 and 2 are in multiple and when raised connect the trolley with the contactors controlling the resistance leads. Con-



INTERIOR OF 160-TON B. AND O. ELECTRIC LOCOMOTIVE.

General Electric Company.

tactor 3 connects R to the line while contactor 11 places the two motors in series. The motors then operate with all of the resistance in circuit. When contactor 2 raises, it opens the switch immediately below it, making it impossible for the reverse to operate while current is flowing through the motors. On the second notch of the controller an additional path is opened by way of finger 3 of the controller. This path leads from finger 3 through four of the control circuit rheostat coils, through contactor No. 5 and to ground over 32. On the 3rd, 4th and 5th points contactors 6, 7 and 9 respectively are raised. The motors are then in full series. Between the 5th and 6th points all the control circuits are broken preparatory to starting the multiple connections of motors. On the 6th or the first multiple point the ground through finger 1 of the master controller is opened while a ground through finger 3 is established. The current from the reverser then, after raising contactors 1 and 2 as before, instead of passing through contactors 3 and 11, passes through the coils of 4, 12 and 13, through the switch under contactor 11 and to ground over finger 2. Contactor 12 connects motor No. 2 to R_7, while contactor 13 grounds No. 1 motor. The motors now operate in parallel and on successive notches of the controller, contactors 6, 7, 8, and 9 are raised, cutting out all of the resistance. The switches underneath contactors 11 and 12 make it impossible for 11 to raise with 12 and 13 or vice versa. The reason for this arrangement is very evident, as a direct ground for R_7 would result.

The Westinghouse Electro-Pneumatic System of Control. In this system of multiple unit or train control, the current to the motors is supplied through a set of unit switches or circuit breakers which are sometimes placed in a circular case or turret underneath the car and in other cases are ranged in a row under the car. The opening and closing of these unit switches is done with compressed air acting on a piston in an air cylinder. When the circuit is to be closed, compressed air is admitted behind the piston and forces it down against the tension of a seventy-pound spring, and the contacts are brought together. When the switch is to be opened, the air is let out of the cylinder and the spring forces the piston back. The air supply is obtained from the storage tanks of the air brake system. The valve controlling the air supply to the cylinder of each unit switch is operated by electromagnets which derive current from a seven cell, fourteen-volt, storage battery. The small master controller operated by the motorman, makes and breaks the battery connections to the magnets controlling the air valves.

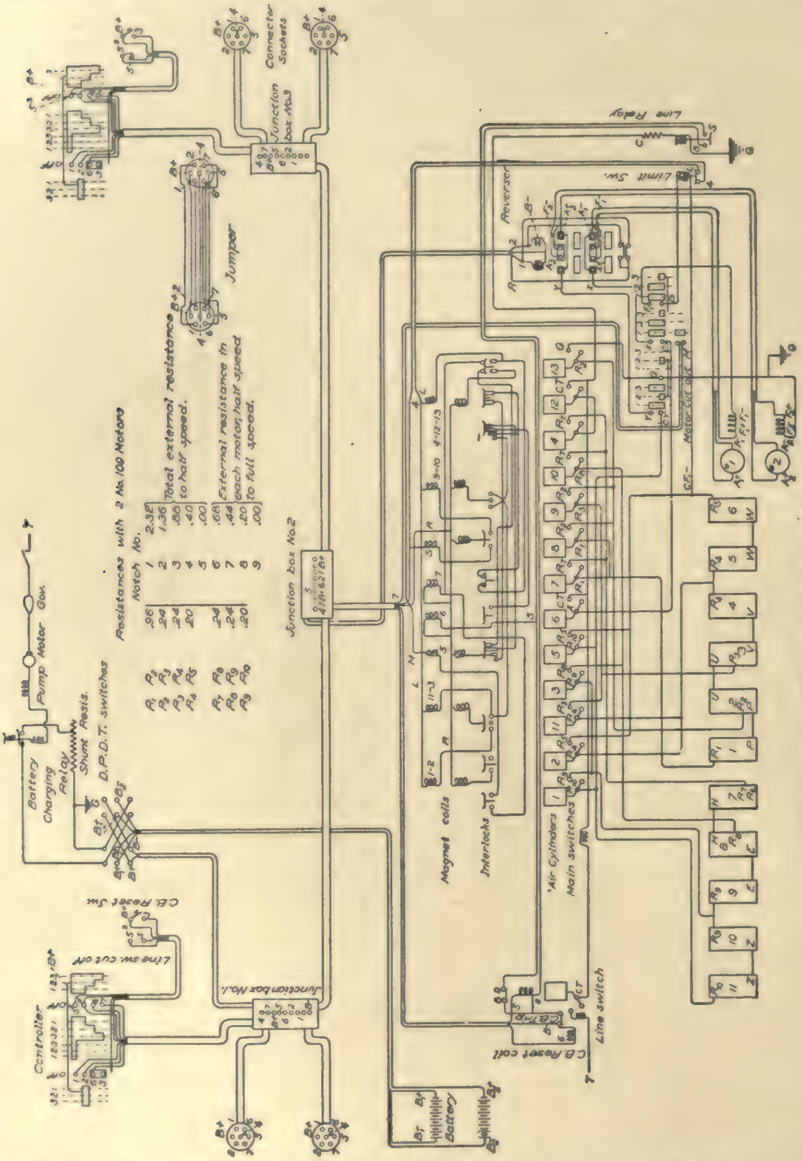


Fig. 28b. Car Wiring for Westinghouse Control System.

An advantage of this over other multiple-unit systems is that by the use of battery current the control system is not disturbed by interruptions of the main supply of current. The chief advantage of this is that it makes it possible to reverse the motors and operate them as brakes in emergencies at all times.

The battery is charged from the main line through lamps as resistance, or may be charged by being connected in series with the air compressor motor.

In the accompanying diagram, Fig. 28 *b*, there are two batteries shown which are charged in series with the compressor motor. By means of two double-pole, double-throw switches, first one and then the other battery is connected for charging and for service. The battery is charged in shunt with a resistance and a relay is connected in the circuit as shown, so as to open the battery circuit whenever the current through the motor stops, and thus prevent the battery discharging through the resistance.

The master controller has a double set of segments in order to decrease the length of the shaft. The handle, therefore, is moved only one-sixth of a revolution from off to full speed. The various circuits can be traced by the letters and numbers each wire bears, so that the circuits will not be gone over in detail. The first position of the master controller throws the reverser switch in the proper direction and also closes the main circuit breaker. On the second point the motors are connected in series with all resistance in circuit, and these resistances are automatically cut out one by one. On the next point of the controller the motors are in multiple and the resistances are automatically cut out in a similar manner. The automatic cutting out of resistances is accomplished by a limit switch in conjunction with operating and holding coils on the electro-pneumatic valves. This limit switch is a kind of a relay which has the current from one of the motors flowing through its coil and which acts to open a certain battery circuit which operates the electro-pneumatic valves whenever the current in the motor circuit in question exceeds the amount for which the limit switch is set. The automatic acceleration or cutting out of resistance is accomplished as follows:

Each electro-pneumatic valve has two magnet coils, one of which is an operating coil and the other a holding coil for holding the valve open after it is operated. When first the current flows through a circuit to one of the electro-pneumatic valves, it flows through the operating coil and operates the valve to close the corresponding switch or switches of the main circuit by turning the air into the cylinders. As soon as the main switch is closed, it cuts into circuit the holding coil of its corresponding electro-pneumatic valve and this coil will, with the battery current, hold the switch closed even though the circuit to the operating coil may be opened momentarily by the limit switch as each step of resistance is cut out. This prevents the switches from opening when they are once closed and allows the operating coils to open an air valve each time the current through the limit switch coil falls below the amount for which it is set. The contacts which close the holding coil circuit on each valve whenever a main switch is closed, are called interlocks and are indicated on the diagram.

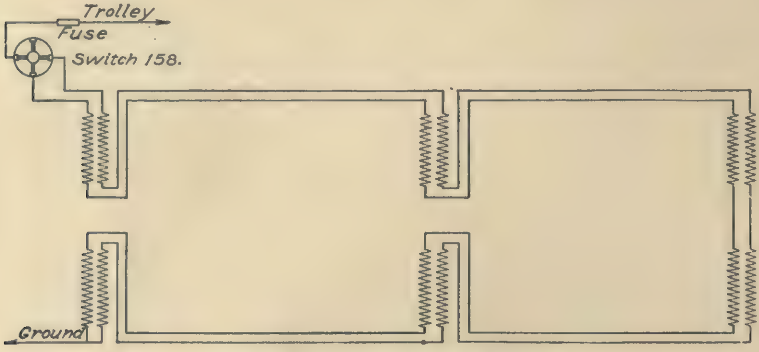
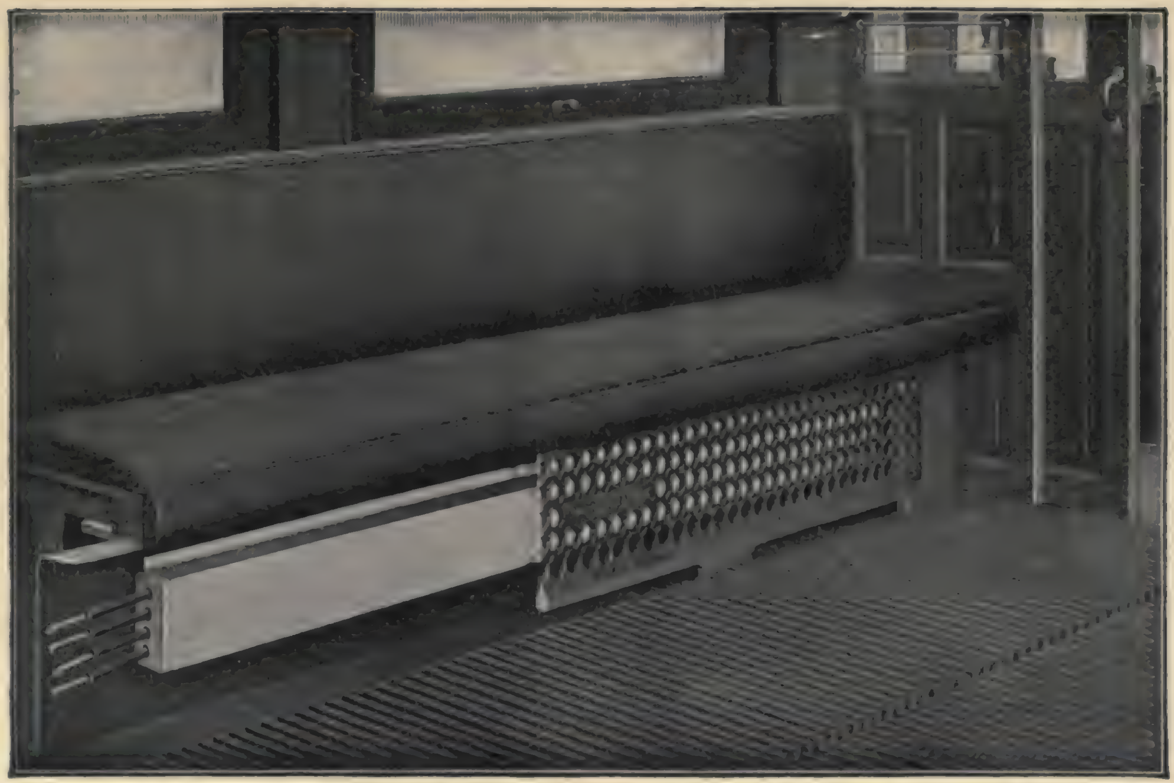


Fig. 29. Diagram of Electric Heaters.

The main line circuit breaker, which is electro-pneumatically operated, will open automatically on overload and can be reset by the motorman on all the cars of a train by closing a switch located beside each controller.

CAR HEATERS.

Electric Heaters for warming cars in winter, consist of iron wire coils which are warmed by the passage of electric current through them. The heat so evolved varies as the resistance multiplied by the square of the current. The iron wire coils of the heater are mounted on non-combustible insulating supports, and are arranged



SEAT OF CAR SHOWING HEATER.

Westinghouse Air Brake Co.

so that there is a free circulation of air through them. The coils are surrounded with a perforated metal case, the object of which is to prevent injury to the coils and to prevent persons or clothing coming in contact with the hot, live wires of the coils. Heaters are sometimes arranged so that they can be connected in series or parallel to give different degrees of heat.

The diagram, Fig. 29, shows the most common arrangement of electric heaters recently. The tap from the trolley should be taken off on the trolley side of the circuit breaker. After passing through a fuse the circuit goes to the switch. Each of the heaters contains two coils, one of higher resistance than the other. Two independent circuits are run from the switch, through the heaters and to the ground. One circuit passes through the high resistance coils of the several heaters while the other goes through the low resistance coils. The switch has three points. On the first point a circuit is made through the high resistance coils. The second point connects the low resistance coils while the third point puts both circuits in service. With this arrangement three gradations of heat may be obtained.

To avoid complicated wiring sometimes but one circuit is employed. In such a case the heat must either be all on or off, no gradations being possible.

The chief difficulty encountered with electric heaters is the breaking of the wires because of the scale of oxide that forms gradually when they are run at a high temperature or because of water striking them from passengers' clothing on wet days, which causes the wires to snap.

The Consolidated Car Heating Company gives the following data on the current required to heat cars:

	Length of Car Body.	Amperes.		
		Switch Positions.		
		1	2	3
Average conditions....................	14 to 20 feet	3	4	7
	20 to 28 "	3	6	9
	28 to 34 "	4	7	11
Severest conditions.	18 to 24 feet	4	7	11
	28 to 34 "	6	8	14

In his Electrical Engineers' Hand Book, Mr. Foster gives results of tests made on Brooklyn cars as follows:

Cars.			Temperature F.		Consumption.	
Doors.	Windows.	Contents cu. ft.	Outside.	Average in car.	Watts.	Amperes at 500 volts.
2	12	850½	28	55	2295	4.6
2	12	850½	7	39	2325	4.6
2	12	808½	28	49	2180	4.3
2	12	913½	35	52	2745	4.5
4	16	1012	7	46	3038	6.
4	16	1012	28	54	3160	6.3

When not watched carefully considerable current may be wasted by allowing the heaters to remain turned on when not needed. Many companies hang out signs where motormen may observe them, indicating when the heaters shall be turned on and to what point.

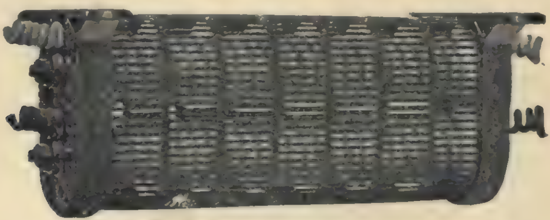


Fig. 30. Electric Heater.

The best practice in electric heating is to have plenty of heaters and run the wire at a low temperature, rather than attempt to heat with a few at high temperature. The greater the number of heaters the larger the radiating surface around which the air can circulate and a given amount of car heating can be accomplished with less current than with a few high temperature heaters. The depreciation of the heater wires is less the lower the temperature at which they are operated. An electric heater is shown in Fig. 30.

Hot-Water Heaters are frequently used on large electric cars. Hot-water pipes are placed along the sides of the car, and connected with a stove containing hot-water coils at one end of the car. The water, as it is heated in the stove or heater, expands, and consequently becomes lighter per cubic inch or other unit of volume; it therefore tends to rise when balanced against the colder water in the car pipes.

Hot water leaves the top of the heater, flows up to an expansion tank and then down through the car piping, and back to the bottom of the heater. The car piping slopes continuously down from the top connection to the bottom connection of the heater. At the top, an opening to the atmosphere is provided through a small water tank, called an *expansion tank*. This prevents water pressure bursting the pipes as they become heated, and allows any steam that may have formed to escape. The most modern hot-water heaters for cars are completely closed except as to the ash pit at the bottom and a small feed door in the top. The latter is locked so that the fire cannot come out even if the car is tipped over in a wreck. Fig. 31 shows the pipes of a hot-water heating installation.

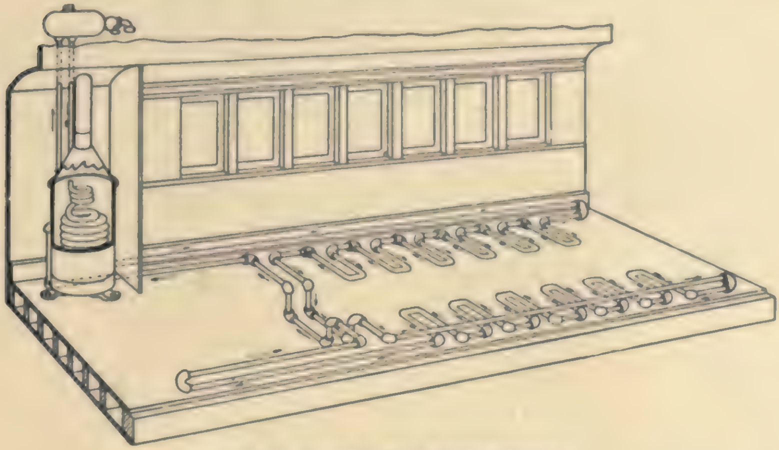


Fig. 31. Pipes for Hot-Water Heating.

CAR WIRING.

The wires from motors to controllers, when placed in exposed position under the car, are bunched in cables or covered with hose. In some cases special runways are provided in the bottom of the car to accommodate the car wiring. All the wiring in a car should be heavily insulated with moisture-proof rubber-covered wire, and further protected from mechanical abrasion by a tough outer covering.

Stranded rubber insulated wire is used almost exclusively for wiring all parts of the car. A general idea of the path of the motor circuit wiring may be obtained by reference to Fig. 22. The main lead after leaving the trolley stand is cleated to the trolley board on top of the car. At the end of the car it passes through the roof and to the circuit breaker. On leaving the breaker it is led down a post, through the floor and to the choke coil and lightning arrester underneath the car. It then passes to the trolley terminal of the controller.

The tap for the light wiring (although shown otherwise in the drawing) is usually taken off the main circuit before the circuit breaker is reached. This arrangement allows the lamps to be burned when the circuit breaker is open. After passing through fuses and switches in the motorman's cab the circuit for the lights is led through the car in moulding concealing it.

The wires running between the motors, controllers and resistance frames underneath the car, as has been stated, are often carried in canvas hose. Usually two cables are made up, for should all the wires necessary be placed in one cable this would become too bulky to be properly cleated up. To make the canvas hose waterproof and to prolong its life it is usually given several coats of asphaltum paint.

The wiring of the new cars of the New York subway is an example of the most advanced practice. All the wires under the cars are carried in "loricated" conduit, which consists of a wrought-iron tube heavily enameled both inside and out. The motor leads and the other larger wires are carried in separate conduits. The conduits are usually hung to the steel beams of the floor framing by strap bolts. This method of wiring gives a reasonable assurance that it will not become defective. Moreover, it lessens fire risk. The conduits are all grounded and should one of the wires come in contact with the conduit carrying it, the dead ground resulting would cause the fuse to blow instantly, and all danger would cease.

RESISTANCES.

The type of resistance now most common for heavy motor equipment is in the form of cast-iron grids, which are assembled together and connected in series. These grids are sufficiently stiff to render unnecessary any solid insulation between them, and hence they can radiate heat to the best advantage. The only difficulty experienced with them is from the warping or cracking. Resistances for lighter equipment are composed of sheet-steel ribbons wound in coils. Each turn of a coil is insulated from the next by asbestos. Other forms of sheet-steel resistance with asbestos insulation between the turns, have also been used. In Fig. 32 is shown a Westinghouse grid type diverter for street railway equipment.

ELECTRIC CAR ACCESSORIES.

Canopy Switch. An overhead switch, sometimes called a "canopy switch," is commonly placed over each street-car platform where a controller is located, usually in the deck or canopy above the motorman's head. This is simply a single-point switch that may be used by the motorman to cut the trolley current off from the controller wiring so that the controllers will be absolutely dead. When two such switches are used, one on each end of the car, they are connected in series.

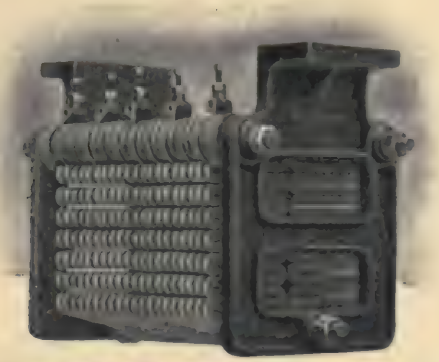


Fig. 32. Grid Type of Resistance.

Car Circuit Breaker. Frequently on large equipments an automatic circuit breaker is provided instead of this overhead switch. This circuit breaker can be tripped by hand to open the circuit whenever desired; and is also equipped with a solenoid magnet, which can be adjusted so that it will trip or open the circuit breaker at approximately whatever current it is set for. This circuit breaker protects the motor and car wiring from excessive current, such as would occur in case of a short circuit in motors or car wiring, or in case the motorman turned on current so rapidly as to endanger the windings of the motors. Circuit breakers, however, are most commonly used on cars having controllers located at only one end in a motorman's cab.

Wiring of Circuit Breakers and Canopy Switches. Figs. 33, 34, and 35 show the methods of wiring circuit breakers and canopy switches for double-end cars.

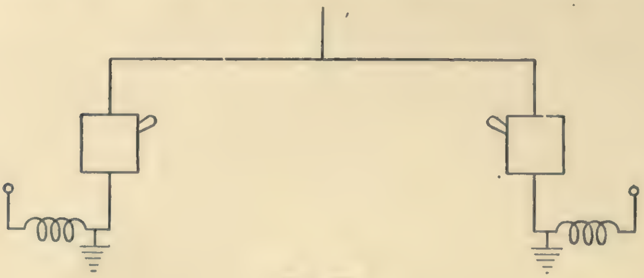


Fig. 33.

In the parallel connection as shown in Fig. 33, the trolley leads after passing through the choke coils go directly to the blow-out coil of the controllers. Aside from the fact that two lightning arresters and choke coils are required, this method is preferable for automatic circuit breakers.

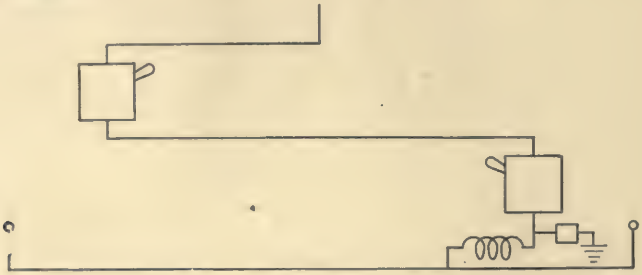


Fig. 34.

Fig. 34 shows the hand-operated circuit breakers connected in series. This method is used where non-automatic breakers are employed, but for automatic breakers it has the objection that an overload would throw the breaker set at the lowest point. This might be the breaker on the opposite end to that occupied by the motorman and in such an event would necessitate a trip to the other end to set the breaker.

Fig. 35 shows a method of parallel connection requiring but one lightning arrester. This method has the objection that the motorman on the front end would have no assurance that by throwing the breaker over him the power would be cut off. The rear breaker might have been carelessly left set.

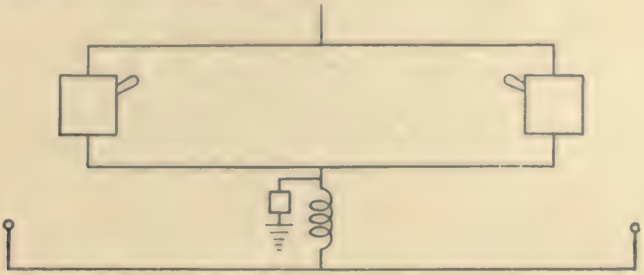


Fig. 35.

Fuses. A fuse is placed in series with the motor circuit before it enters the controller wiring, but where circuit breakers are used instead of canopy switches, the fuse box may sometimes be dispensed with. The fuse box on street cars is usually located underneath one side of the car body where it is accessible for replacing fuses, but where a motorman's cab is used, the fuse may be placed in the cab. The fuse may be of any of the types in common use, either open or enclosed. In the Westinghouse fuse box it is necessary only to open the box and drop in a piece of straight copper wire of the right length and size. The closing of the box clamps this wire to the terminals and establishes a circuit through the copper wire as a fuse. Of course this copper wire is of small enough size to be fused by a dangerously heavy current.

Lightning Arresters. A lightning arrester is used on all cars taking current from overhead lines. The lightning arrester is connected to the main circuit as it comes from the trolley base, before it reaches any of the other electrical devices on the car, so that it may afford them protection. A common type of lightning arrester is shown in Fig. 36. One terminal of the

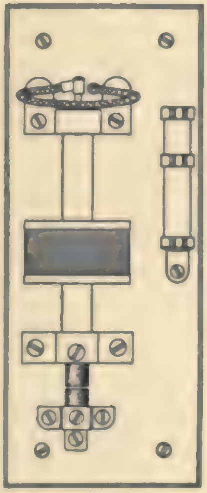


Fig. 36.

lightning arrester is connected to the motor frame so as to ground it, and the other is connected with the trolley. In most forms of lightning arrester, a small air gap is provided, not such as to permit the 500-volt current to jump across, but across which the lightning will jump on account of its high potential. To prevent an arc being established across the air gap by the power house current after the lightning discharge has taken place and started the arc, some means of extinguishing the arc is provided. In the General Electric Company's lightning arrester, the arc is extinguished by a magnetic blow-out, which is energized by the current that flows through the lightning arrester. The instant the discharge takes place the current flows across the air gap. The magnetic blow-out extinguishes the arc, and this opens the circuit, leaving the arrester ready for another discharge. In the Garton-Daniels lightning arrester a plunger contact operated by a solenoid opens the circuit as soon as current begins to flow through the arrester. This plunger operates in a magnetic field, which extinguishes the arc. A choke coil, consisting of a few turns of wire around a wooden drum, is placed in the circuit leading to the motors at a point just after it has passed the lightning arrester tap. This choke coil is for the purpose of placing self-induction in the circuit, so that the lightning will tend to branch off through the lightning arrester and to ground, rather than to seek a path through the motor insulation to ground.

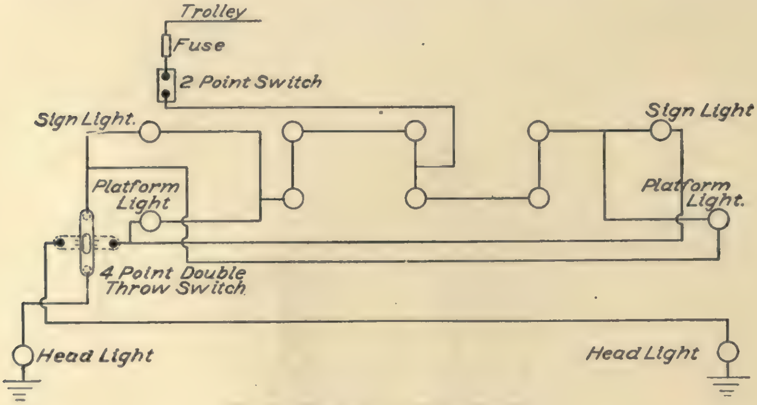


Fig 37. Diagram of Light Circuit.

Often, however, the choke coil is omitted, the coils in the circuit breaker and the blow-out coil in the controller being depended upon to prevent the lightning charge from passing.

Lamp Circuits. The lamp circuit of a car is protected by its separate fuse box, and usually each lamp circuit has a switch. As explained before, five 100-volt or 110-volt lamps are placed in series between the trolley wire side of the circuit and ground. If one lamp in the series burns out, of course, all five are extinguished until the defective lamp is replaced with a new one. Enclosed arc lamps are sometimes used for car lighting.

Cars to be operated from either end are often wired so that by turning a switch the platform light on the front end, a light for the sign and another for the headlight on the rear end will be extinguished and corresponding lights on the rear and front ends lighted. This is accomplished by the method of wiring shown in Fig. 37. The interior of the car is lighted by six lights. Headlights of 32 candle power are used. This method requires the use of two switches. In all light wiring schemes a switch should be placed on the trolley side of the lights. This permits the current to be cut off in the event of a ground occurring in the system.

On interurban cars arc headlights are almost invariably used The circuit for the headlight after passing through a switch in the motorman's cab goes through a resistance frame usually underneath the car and terminates in a socket near the car bumper. The brackets on which the lamp is hung are grounded so that whenever the plug from the lamp is inserted in the socket and the switch in the cab is turned on, the circuit is made.

Usually there is a pressure of about 60 to 70 volts at the terminals of the lamp. The remainder of the voltage drop, from 500 or 600 volts (or whatever the line may be), is in the resistance under the car. The current through the lamp is usually about four amperes. With 60 volts at the arc and 500 volts on the line, this gives a consumption in the lamp of 240 watts and a loss in the resistance under the car of 2,000 watts, or about 90 per cent. The use of the headlight resistance to cut the voltage down is therefore a very inefficient method. Some schemes of wiring use the incandescent lamps used in lighting the car as resistance for the headlight. Another way is to light the interior of the car with arc lamps placed in series with the arc headlight.

Trolley Base. The trolley base upon which the trolley pole swivels, and which furnishes the tension that holds the trolley wheel against the wire, is designed to maintain, by means of springs, an approximately even tension against the trolley wire, whether the trolley wire is high above the track or near the car roof. This is done by changing the relative leverage which the springs of the trolley base have on the trolley pole according to the height of the trolley pole.

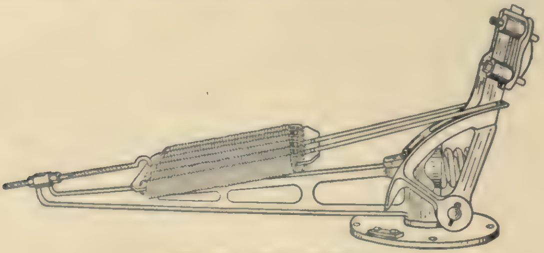


Fig. 38. Trolley Base.

Fig. 38 shows one form of trolley base. The trolley base is bolted to a platform constructed for it on the roof of the car; and the supply wire to the motors and other electrical devices on the car, except in cases where a wooden trolley pole is used for certain special reasons, is connected directly to the trolley base. An insulated trolley wire is run down the wooden trolley pole, and connected through a flexible lead to the car wiring.

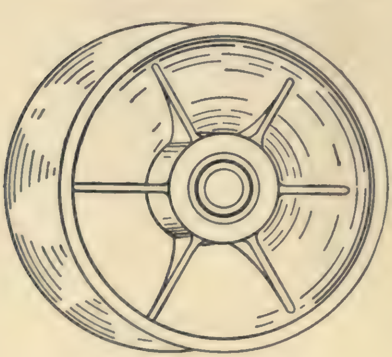
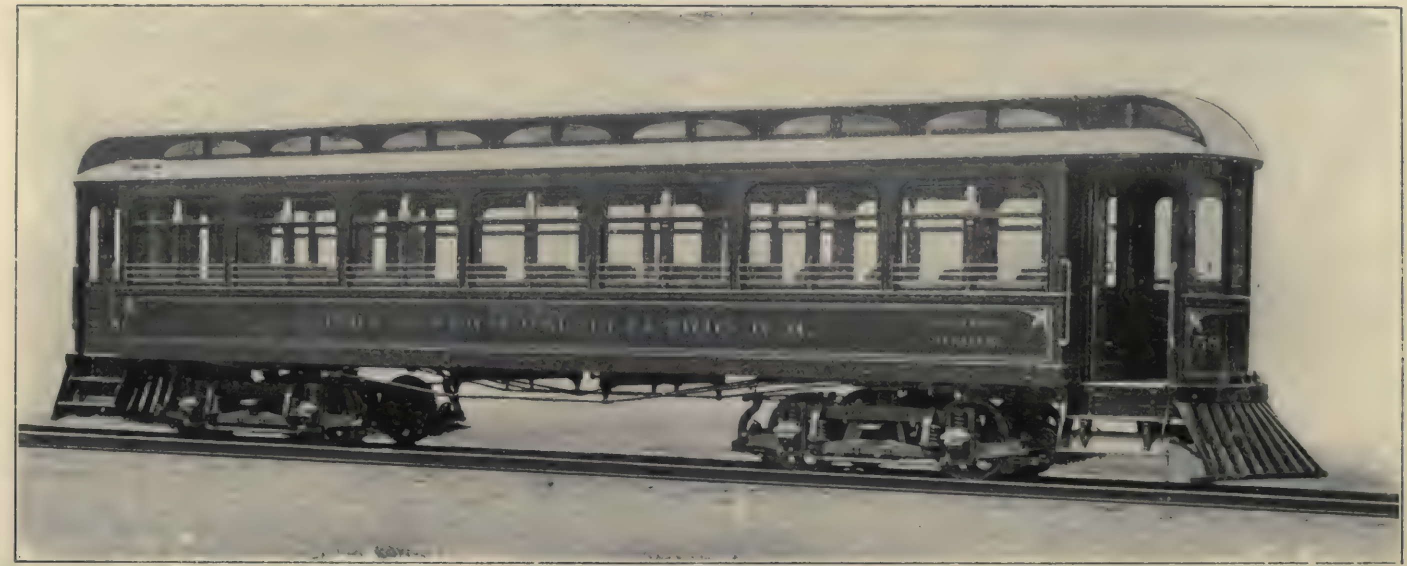


Fig. 39. Trolley Wheel.

Trolley Poles. The trolley poles in general use are of tubular steel, which gives the greatest strength for a given weight, and which can usually be straightened if the pole has been bent by striking overhead work when the trolley wheel leaves the wire.

Trolley Wheels. Trolley wheels are from four to six inches in diameter over all, the small wheels being used in the city service, and the large wheels in high speed interurban service. A typical trolley wheel is shown in Fig. 39. Various companies use various



INTERURBAN TYPE OF CAR.

Speed, 60 Miles per Hour.

J. G. Brill Company.

forms of groove in the trolley wheels, some adopting a groove approximately V-shaped. The U-shaped groove, however, is the most common. The trolley wheel is made of a brass composition selected for its toughness and wearing qualities.

Trolley Harp. The trolley harp, which is placed on the end of the trolley pole and in which the trolley wheel revolves, usually has some means for making electrical contact with the wheel in addition to the journal bearing. In the harp illustrated in Fig. 40, which is a typical form, this additional contact is secured by a spring bearing against the side of the hub of the wheel.

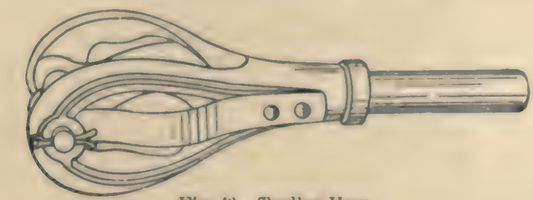


Fig. 40. Trolley Harp.

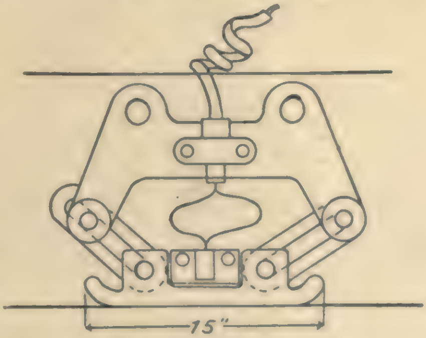


Fig. 41. Third Rail Shoe.

Since trolley wheels revolve at a very high speed, some unusual means of lubrication must be provided, since there is no opportunity for ordinary oil or grease lubrication. Graphite, in the shape of what is called a "graphite bushing," is most commonly used. This is a brass bushing, which is pressed into the hub of the trolley wheel. In this bushing is a spiral groove filled with graphite which is supposed to furnish sufficient lubrication as the bushing wears. Roller-bearing trolley wheels have been used to a limited extent, with considerable success in some cases. Some companies have done away with the graphite bushing, and have provided a very long journal for the trolley wheel instead of the usual short bushing.

Contact Shoes. The contact shoe most commonly used on roads employing the third rail is shown in Fig. 41. This is simply a shoe of cast iron hung loosely by links. The weight of the shoe is sufficient to give contact. The motion of the links permits the shoe to accommodate itself to unusual obstructions and variations in the height of the third rail. The shoe is fastened to the truck frame by means of a wooden plank which furnishes the necessary insulation.

The Potter third-rail shoe which has been used to a limited extent, employs a spring for giving the necessary tension to make electrical contact between the shoe and the third rail. In some ways this is superior, because a spring tension is quicker in its action than gravity, and the shoe accommodates itself better to variations in the height of the third rail at very high speed. The wear on the shoe, however, is likely to be greater.

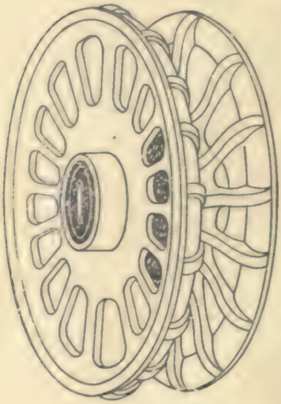


Fig. 42. Sleet Wheel.

Sleet on Trolleys and Third Rails. The deposit of sleet on trolleys and third rails hinders greatly the operation of cars. Often sleet wheels of the type shown in Fig. 42 are used as a trolley wheel. These cut the sleet off instead of rolling over it.

On the third rail, scrapers and brushes in advance of the contact shoe are usually effective where trains are frequent. Several roads are now melting the sleet on the rails by the use of a solution of calcium chloride. The solution is stored in a tank on the car and is led through small pipes to the rail immediately in front of the collecting shoe. About one gallon of solution is used per mile, making the cost about 7½ cents per mile. The effects of one treatment last for two or three hours during the continuance of a storm.

Solutions of common salt have been used in the same manner, but it is claimed that the corroding action on the iron of the calcium chloride is not as great as that of a salt solution.

TRUCKS.

Electric railway cars are classified generally as *double-truck* and *single-truck* cars. Double-truck cars are those that have a truck

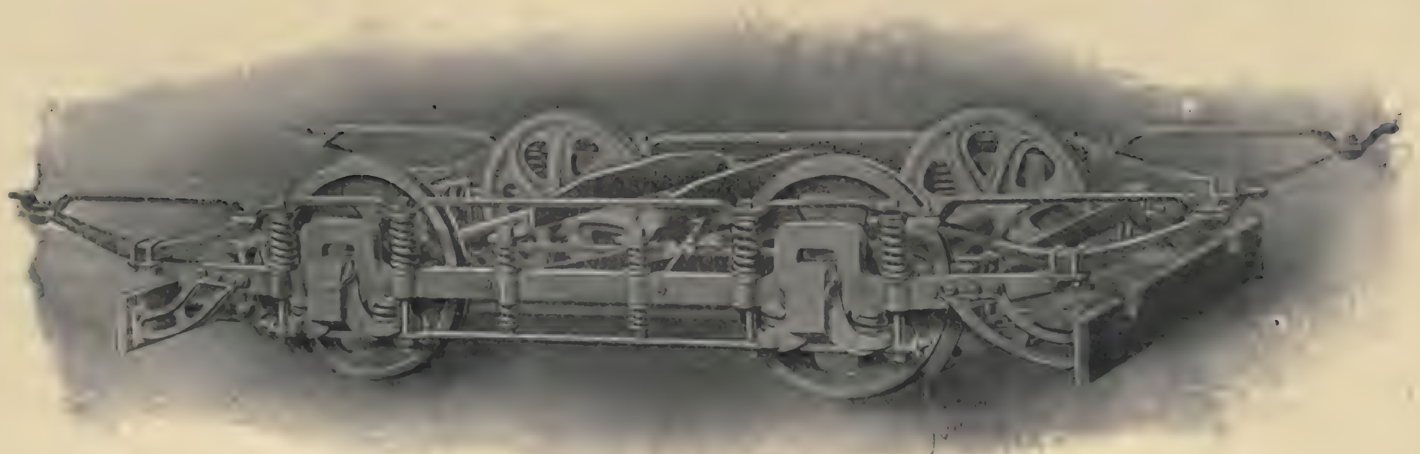


Fig. 48. Brill 21-E Car Truck.

that swivels at each end of the car. A single-truck car is one having four wheels.

Single Trucks. A great many types of single trucks have been designed. It would be out of the question to discuss them all here. In general, however, it may be said that truck builders have aimed to make a truck frame in itself a complete unit independently of the car body, so that the car body will simply rest upon the trucks and there will be no strain on the car body in maintaining the alignment of the truck. Most single trucks, therefore, consist of a rectangular steel frame, either cast or forged, riveted or bolted together. This frame holds the journal boxes in rigid alignment. Usually a spring is placed between each journal box and the truck frame. This spring may be either spiral or elliptic. The principal springs, however, are between the truck frame and the car body. Most truck builders have used a combination of spiral and elliptic springs between the car body and truck frame, as this combination is considered to give better riding qualities and greater freedom from teetering or galloping than either spiral or elliptic springs alone. Fig. 43 shows a Brill single truck, which illustrates all of the features enumerated.

Swivel Trucks. Swivel trucks, commonly called *double trucks*, are made in many forms, but the most common is that known as the M. C. B. type of truck. This truck is similar to the standard truck which is in universal use on steam railroad passenger cars in the United States. Different truck builders have introduced many variations in this general type of truck, in adapting it to electric service. Some modifications from the steam railroad standard truck were necessary to accommodate the electric motors and to permit in some cases a low-hung car body. Such trucks are made in a great variety of sizes.

Fig. 44 shows one of these trucks built by the St. Louis Car Company. In this type of truck the car body is fastened to the truck only by the kingbolt on which the truck swivels. This kingbolt is placed in the center of the truck bolster. There are also side bearings between the car body and the ends of the bolster, to prevent tipping of the car body when it is unbalanced. The arrangement of this part of the truck is shown in Fig. 45. Under this bolster are elliptic springs which rest on what is called the *spring plank*. This

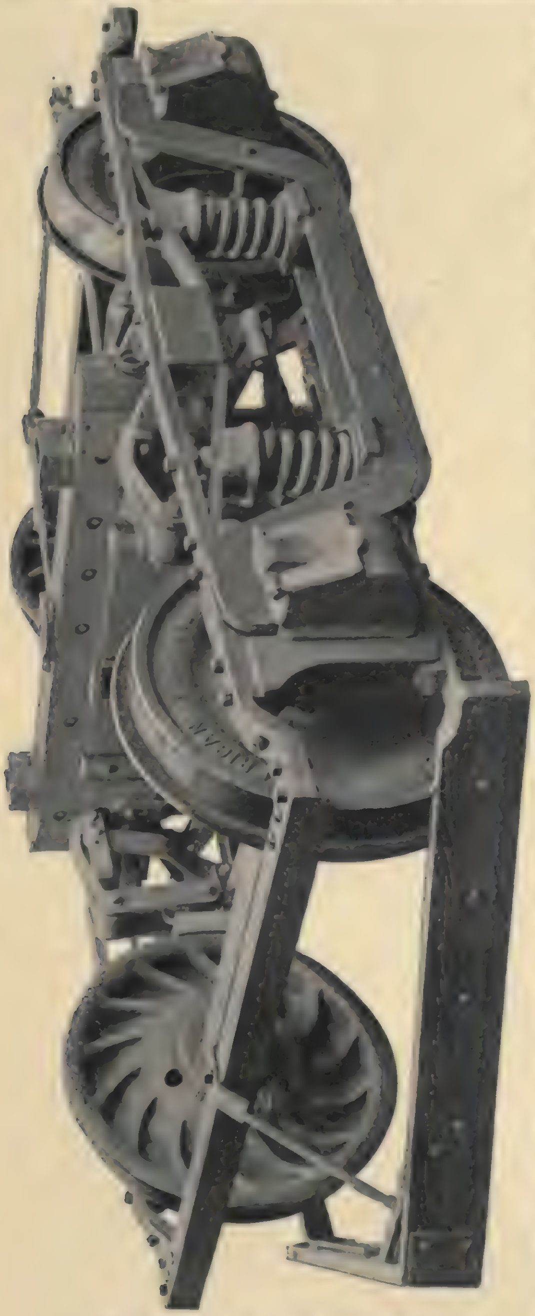


Fig. 11. St. Louis Car Company Truck.

spring plank is hung from the rectangular frame of the truck by links which allow a side motion. This side motion gives easier riding, especially upon entering and leaving curves. All trucks having this feature are known as *swing bolster trucks.* The weight, being transmitted to the transom and truck frame through the swinging links just referred to, is then taken by the equalizer springs that support the rectangular truck frame on equalizing bars, which equalizing bars rest on the journal box at either end and are bent down to accommodate the springs located between them and the truck frame. The truck frame holds the journal boxes in alignment by means of guides which permit an up-and-down movement without movement in any other direction, just as on all other types of truck. It is thus seen that there are two sets of springs between the car body and car journals; one set of spiral springs between the equalizing bar and truck frame; and one set of elliptic springs between the spring plank and the bolster. All shocks must be transmitted first through the spiral springs and then through the elliptic springs. The motors used on this type of truck usually have nose suspension, the nose of the motor resting either on the bolster of the truck or on the truck frame.

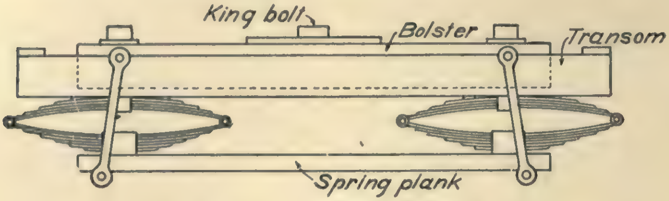


Fig. 45. Bolster, Links and Spring Plank.

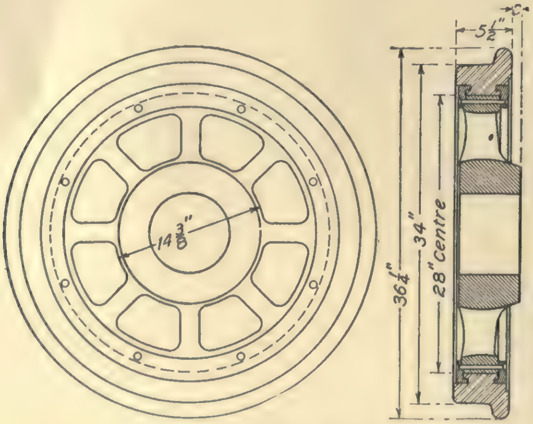


Fig. 46. Steel Tire Wheel.

There are a number of swivel trucks made which have departed considerably from M. C. B. lines, but nearly all retain the features of a bolster mounted by springs on a spring plank, a spring plank hung from a transom, a transom rigidly fastened to the rectangular truck frame of which it forms a part; and a truck frame with one or more sets of spiral springs between it and the journal boxes.

Maximum Traction Trucks. A type of swivel truck that once was very popular but has largely been superseded by the type just described is the "maximum traction truck." This truck has two large wheels on an axle which carries 60 to 70 per cent of the weight on the truck, and two small wheels carrying the balance of the weight. The motors are on the large wheels.

Car Wheels. The car wheels most commonly used are of cast iron. In order to make a tread and flange upon which the wear comes, hard enough to give a good mileage, the tread and flange are chilled in the process of casting. Around the periphery of the mould in which the wheels are cast, is a ring of iron instead of the usual sand. When the molten cast iron comes in contact with this ring of iron, which is called a "*chill,*" the iron is cooled so suddenly that it becomes extremely hard. The balance of the wheel, cooling more slowly since it is surrounded by sand, has the hardness of ordinary cast iron. A steel tire wheel is shown in Fig. 46.

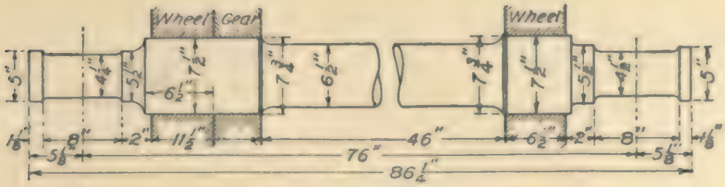


Fig. 47. Elevated Car Axle.

Wheels with steel tires are coming into use for elevated and interurban cars because their flanges are not so brittle as those of cast-iron wheels. In wheels of cast metal there is always a liability that the flanges and tread will chip and crack. On high-speed cars the falling-out of pieces of flange may be a serious matter and result in a wreck. Steel-tired wheels have a hub and spokes either of cast or forged steel or iron. On to this wheel a steel tire is shrunk. The tire is heated in a furnace built for the purpose, and is then slipped over the wheel. It is made just such a size that it will slip over the wheel when hot, and when it is cool it will shrink enough to make a very tight fit. When the tire is to be removed after it is worn out, it is heated until it has expanded sufficiently to drop off.

An axle for elevated car is shown in Fig. 47.

When cast-iron wheels are worn to an improper shape or have flat spots upon them, due to the sliding of the wheels with the brakes set, an emery wheel grinder must be used to grind them down, as nothing else is hard enough to have any effect on the iron.

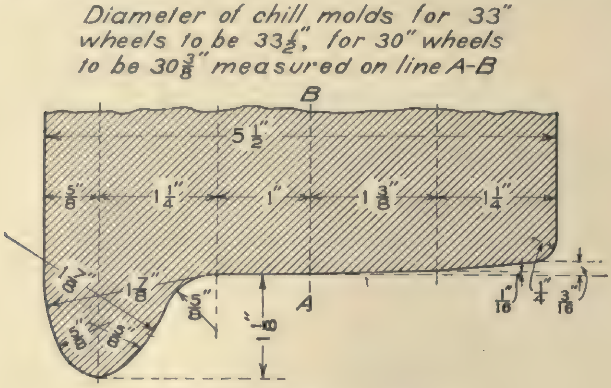

Diameter of chill molds for 33" wheels to be 33½", for 30" wheels to be 30⅜" measured on line A-B
B
5½"
5/8"
1¼"
1"
1⅜"
1¼"
1 7/8"
1 7/8"
5/8"
5/8"
3/8"
A
1/8
1/16"
1/4"
3/16"

Fig. 48. Standard M. C. B. Flange.

When steel-tired wheels are worn, they can be put in a lathe and the surface of the tire turned off, as this surface is of metal soft enough to be workable with ordinary tools.

The types of wheel tread and wheel flange in use vary greatly among different electric railways. There is a standard Master Car Builders' wheel tread used on steam railroads, which is shown in Fig. 48. Electric railways, however, are usually obliged to use a smaller flange and narrower tread. Street railway special work, such as switches and crossings, usually has too shallow a flange

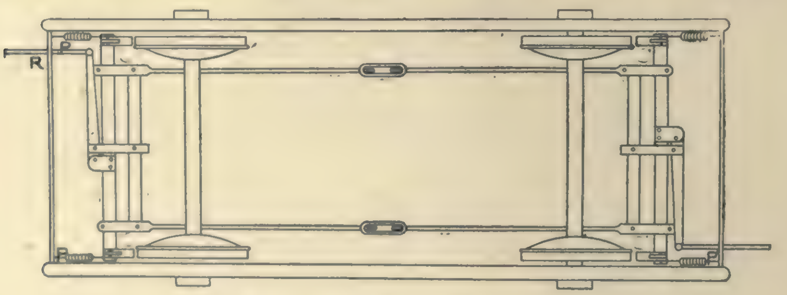


Fig. 49. Brake Shoes and Levers.

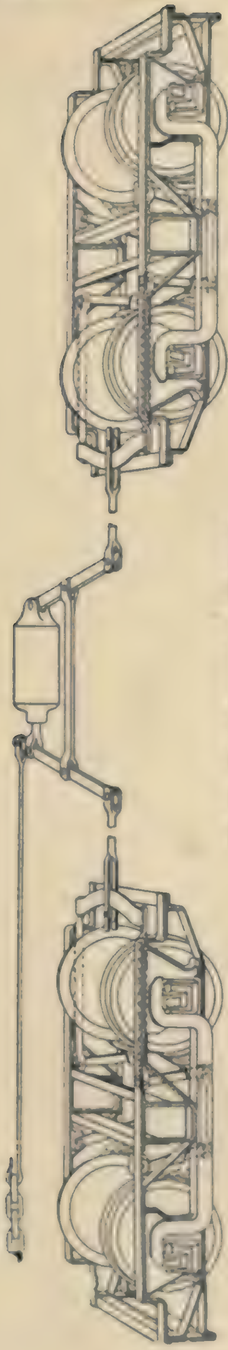


Fig. 50. Brake Levers and Air Brake.

way to permit a standard M. C. B. flange to pass through. Some street railways use flanges as shallow as ⅜-inch, although ¾-inch is most common on city work. The width of the tread on street railway cars, that is, the width of the wheel where it bears on the rail, is usually from 1¾ inches to 2¼ inches. There is a tendency, however, on electric railways, on account of the increasing number of interurban cars which must use city tracks, to build tracks that will accommodate wheels approaching the M. C. B. standard of steam roads. A few roads have adopted wheel treads and flanges very near to the M. C. B. standard.

Brake Rigging. The brake rigging on a single-truck car may be arranged in a variety of ways, but should be such that a nearly equal pressure will be brought to bear on the brake shoes on all four wheels. A typical arrangement of brake shoes and levers for single-truck cars is shown in Fig. 49. The rods R terminate in chains winding around the brake staff upon which the motorman's handle or hand wheel is mounted.

For double-truck cars the brake rigging is necessarily more complicated, as it must be arranged to give an equal pressure on all eight wheels of the car. Brake shoes are sometimes placed between the wheels of a truck and sometimes outside. The arrangement of brake shoes between wheels is apparently finding most favor, as when the shoes are applied in this position there is less tendency to tilt the truck frame when the brakes are applied, and this adds to the comfort of passengers in riding. Fig. 50 shows one form of arrangement of brake levers common on a double-truck car equipped with air brakes, with inside-hung brake shoes.

Brake Leverages and Shoe Pressure. The levers between the air cylinder and the brake shoes are usually so proportioned that with an air pressure of 70 lbs. per sq. in. in the brake cylinders the total of the brake shoe pressures on the wheels will be equal to about 90 per cent of the weight of the car. The diagram Fig. 51 has shoe pressures and strains in the several rods marked on shoes and rods.

The following example, based on the diagram, will explain the lever proportioning. Only round numbers are given on the diagram.

Assume a four-motor car weighing 40,000 pounds. A brake cylinder 7 inches in diameter is used. This gives 38.5 square inches and at 70 pounds air pressure a total force on the piston rod of 2,695 pounds. The weight of the car is 40,000 pounds. Taking 90 per cent of this gives a total of 36,000 pounds to be exerted by the brake shoe when an emergency stop is made. Each of the eight shoes will press against the wheels with a force of 4,500 pounds.

The dimensions of the truck are such that the "dead levers," those fixed at one end and which carry shoes, cannot be over 13 inches long. The shoe will be hung three inches from one end, making the proportions 10 to 3, and the pressure on the strut rod between shoes will be 4,500 × $\frac{10}{13}$ or 3, 461 pounds. To clear the truck frame the live lever extends 14 inches above the point of application of the brake shoe. To obtain 4,500 pounds pressure on the shoe, the distance between the brake shoe and the strut rod, which we will call "x," will be found by regarding the upper end of the lever as fixed and the power applied at the lower end.

$$4500 = 3461 \times \frac{14 + x}{14} \text{ or}$$

$$x = 4.2 \text{ inches.}$$

Now to obtain the force required in the rod to the truck quadrant, the bottom end of the live lever must be regarded as the fulcrum. The equation is

$$x = 4500 \times \frac{4.2}{18.2} = 1038 \text{ pounds.}$$

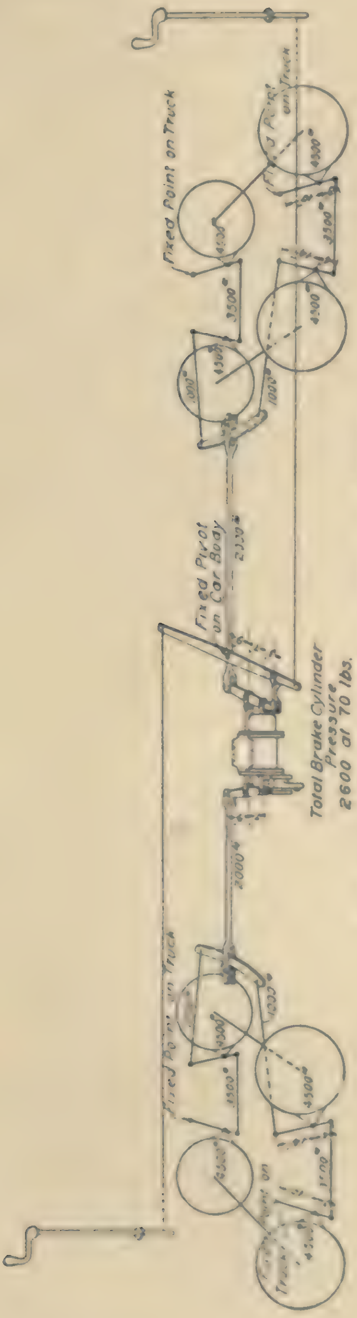


Fig. 51. Diagram of Brake Shoe Pressures and Strains.

As the pull rods from each side of the truck are attached to the truck quadrant, the stresses in the brake rods are double this, or 2,076 pounds.

The position of the brake cylinder under the car restricts the length of the "live" and "dead" cylinder levers to 16 inches. To obtain 2,076 pounds pull on one end of the levers with the previously computed 2,695 pounds on the other, the proportions must be $\frac{2076}{4771} = \frac{x}{16}$, since $2076 + 2695 = 4771$. Then $x = 7$ inches, the distance from the brake piston to the pivotal point.

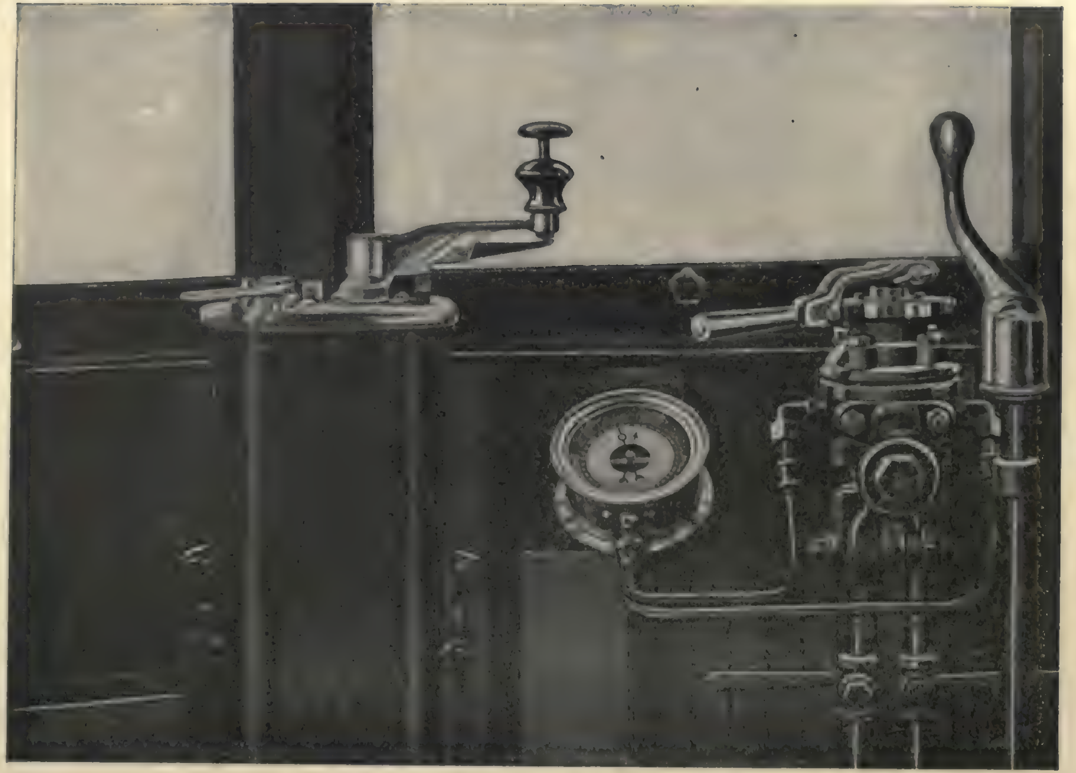
Since 2,695 pounds pressure is exerted and 36,000 pounds results the proportion of the whole system of levers is 36,000 to 2,695 or 13.3 to 1. In other words the travel of the piston in the cylinder will be 13.3 times that of the shoes if there were no lost motion to be taken up. The piston travel should be from 4 to 5½ inches. This gives about ⅜-inch travel of the brake shoes. Increased travel of the brake shoes necessary to set them as they wear away causes increased travel of the piston of the air cylinder. Not only is more air used at each application of the brakes but the brakes are slower in acting. It is therefore necessary to adjust the brakes frequently. This is done in the system shown in the diagram by the use of a turnbuckle in the connecting rod between the live and dead levers of the truck.

When two motors are on one truck and none on the other, allowance must be made in the levers for the increased weight of the motor truck and the inertia of the armature. The leverage on the motor truck must be greater than on the other.

Air Brakes. Air brakes used on electric railway cars are usually of what is called the *straight air brake* type in distinction to the *Westinghouse automatic air brake.* A straight air brake is one in which the air is stored in a reservoir; and, when the brakes are to be applied, air from this reservoir is turned directly into the brake cylinder, in which works a piston operating the brake levers. Air admitted behind the piston forces it out with a pressure which applies the brakes. When the air is let out of the brake cylinder, a spiral spring forces the piston back to its original position and the brakes are released. The motorman's valve by which he applies the brakes, therefore, provides, first, for turning air from the storage reservoir to the brake cylinder to apply the brakes, and, second, for closing the opening to the storage reservoir and opening an exhaust passage from the brake cylinder so that the air can escape from the brake cylinder to release the brakes.

Straight air brakes of this kind would not be suited to the operation of long trains, because, if the air-brake hose connection between cars should be broken, the brakes would be useless; but for trains of one or two cars, such as are common in electric railway practice, the simplicity of the straight air brake outweighs its disadvantages and this is the type of brake usually employed. (See Fig. 52.)

The Westinghouse and other forms of automatic air brake are used on electric railways where cars are operated in long trains; but it is out of the province of this paper to describe these brake systems fully, as they are rather complicated. It may be said in general, however, that the Westinghouse automatic air brake is so arranged that, should the hose connection between cars be broken, should the train pull in two, or should anything happen to reduce the pressure which is maintained in the train pipe that runs the length of the train, the brakes would immediately be applied on the entire train.



AUTOMATIC AIR BRAKE CAB EQUIPMENT.

Westinghouse Air Brake Co

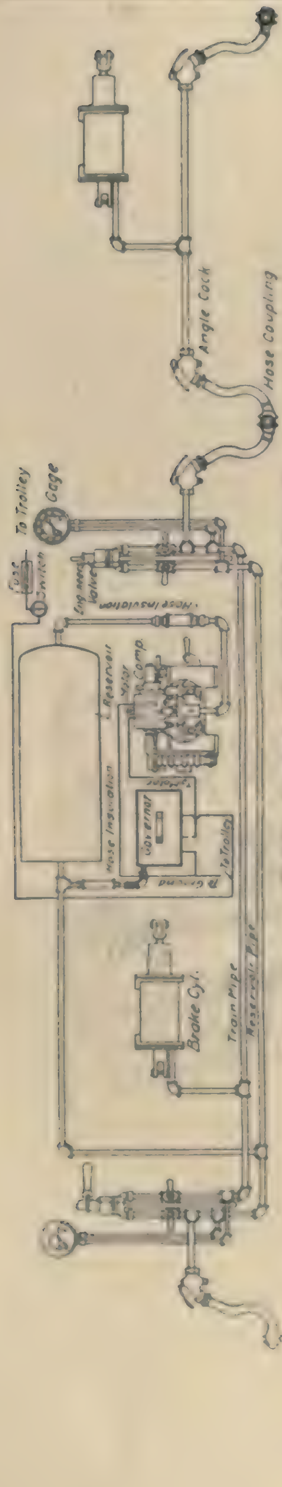


Fig. 52. Diagram of Straight Air Equipment.

Compressors. A small air compressor driven by an electric motor is frequently employed on electric cars to keep the storage reservoir of the car supplied with air. These air compressors are carried under the car or in the motorman's cab. They are generally arranged with an automatic device which closes the motor circuit and starts the motor as soon as the air pressure falls below a certain amount; and the motor will continue in operation pumping air until the pressure rises to the amount for which the automatic device is set. The pressure carried in the storage reservoir is usually from 60 to 90 pounds per square inch, which, as a general thing, is considerably more than is required to apply the brakes hard enough to slide the wheels.

Automatic Governor for Air Compressors. Automatic governors are often installed in connection with air compressors in order that a fairly even air pressure may be maintained in the storage reservoir. In these the fall and rise of the air pressure within certain limits closes and opens the circuits to the motor. In some styles the air acting on a piston operates the circuit breaker.

The diagram shown in Fig. 53 shows the principle of the Christensen governor, in which the air pressure is employed to make and break a secondary circuit.

When the pressure in the storage reservoir falls below a predetermined value, the hand of the air gauge makes contact with lug A. This closes the circuit through solenoid No. 1. Lug D, mechanically connected to the armature of the solenoids is pulled in contact with lug C, and this closes the circuit to the motor, and shunts the winding of solenoid No. 1. When the air pressure rises to a predetermined value the hand of the air gauge is thrown in contact with lug B. This energizes solenoid 2 by connecting it across the motor terminals. The armature is pulled to the right and the circuit to the motor is broken. When this is done it is evident that the current through the energized solenoid is broken. It is evident from the description that current passes through the solenoids

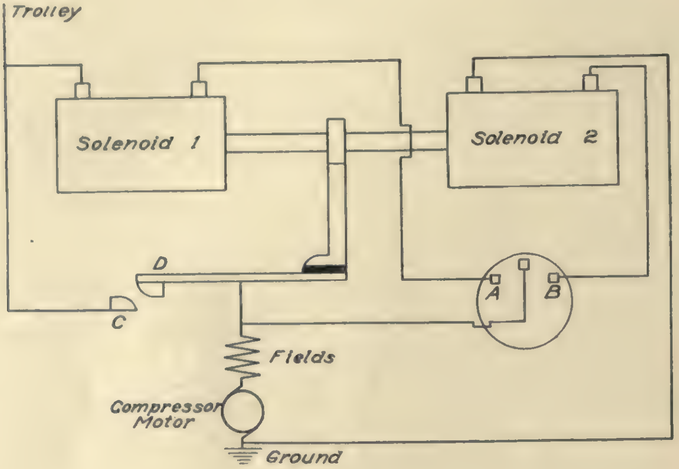


Fig. 53.

only during the short periods that the armature is moving from one position to the other and the air gauge never has to break a circuit in which there is an appreciable voltage so that there is no arcing at lugs A and B.

A blow-out coil in series with the motor is provided immediately under lug C which extinguishes the arc at that point when the motor circuit is broken.

A Westinghouse air compressor is shown in Fig. 54.

Storage Air Brakes. The storage air-brake system does not have a small independent compressor on each car, but is equipped with a large storage tank, in which air is carried under high pressure—250 to 300 pounds per square inch. This storage tank is filled at regular intervals when the car passes some point on its route at which a compressor is located. In this case the car is obliged to stop long enough to make connection to the tank of the compressor plant, and to allow the car storage tank to be filled. This operation, however, does not take long. The advantages of the system are a saving of the weight and a saving in the maintenance of a small compressor on each car. From the main storage tank under the car, air is led through a reducing valve to an auxiliary storage tank. This reducing valve allows enough air to pass through to maintain a pressure of about 50 pounds per square inch in the auxiliary storage tank. The auxiliary storage tank corresponds to the regular storage tank on a system employing compressors on each car. The method of operation after the air has entered the auxiliary storage tank is the same as with any air-brake system.

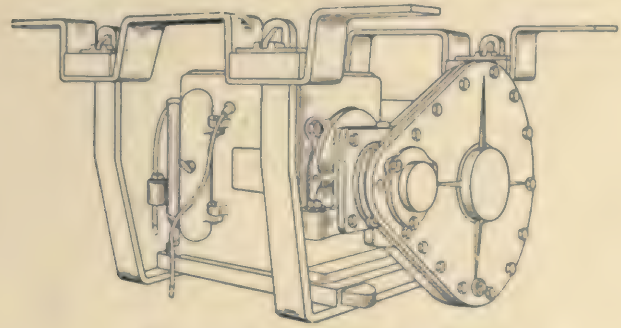


Fig. 54. Westinghouse Air Compressor.

Fig. 55 shows the arrangement of the apparatus under the cars of the St. Louis Transit Company. The two storage tanks are each 6 feet long by 18 inches in diameter and are mounted one on each side of the car. Their combined capacity is equivalent to about 100 cubic feet at 45 lbs. pressure. The tanks are charged through an outlet near one side of the car. This outlet contains a check valve and cock to prevent leakage.

The service or low pressure reservoir has a capacity of about 2½ cubic feet. The position of the reducing valve between the high and low pressure valves may be noted in the illustration.

Momentum Brakes. Momentum or friction brakes have been used to some extent both on single-truck and on double-truck cars, but particularly on single-truck cars. They derive the power to operate the brakes from the momentum of the car by means of a friction clutch on the car axle. The difference in various kinds of momentum brakes lies chiefly in the design of the clutch mechanism. The clutch must evidently be arranged to act very smoothly, and must be under very accurate control, as the force with which the brakes are applied depends directly upon the pull exerted by the clutch.

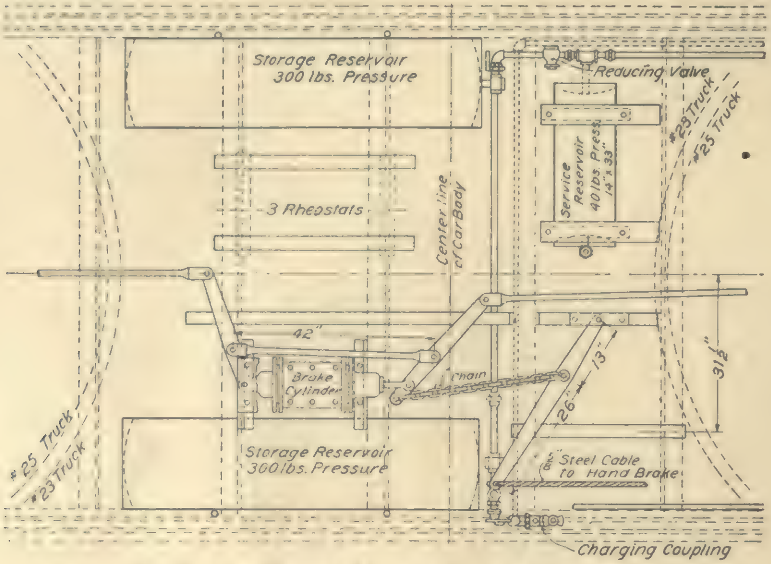

Storage Reservoir 300 lbs. Pressure
Reducing Valve
#23 Truck
#25 Truck
Service Reservoir 40 lbs. Pres. 14"x33"
3 Rheostats
Center line of Car Body
42"
Brake Cylinder
Chain
13"
26"
31½"
⅝" Steel Cable to Hand Brake
Storage Reservoir 300 lbs. Pressure
#25 Truck
#23 Truck
Charging Coupling

Fig. 55. Arrangement of Storage Air Brake Apparatus.

In the Price momentum brake a flat disc is cast on the car wheel, which is turned off to a smooth surface. Against this disc a friction clutch acts, which has a leather face. The clutch is operated by a motorman's lever through a set of levers. A small movement in the motorman's lever forces the clutch against the disc on the car axle. The clutch winds up the brake chain, and thus supplies power to apply the brakes.

Other momentum or friction clutch brakes have been devised, most of which also use an application of leather on iron for the clutch, as this has been found to be most reliable, and to be least affected by the grease and dirt that is liable to work in between the clutch surfaces.

G. E. Electric Brake. The General Electric Company's electric brake makes use of current generated by the motors acting as dynamos, to stop the car. In order to accomplish this, a brake controller is provided which reverses the armature connections of the motors, and so connects them to operate as dynamos sending current through a resistance in the circuit; the amount of current flowing and the braking effect depending on the car speed and the resistance In some forms of brake controller, the two controllers are combined in one cylinder, so that the motorman, to apply the electric brake, simply continues the movement of the handle past the "off" position. In others, the brake-controller drum is separate, but is interlocked with the main controller so that it can be used only when the main controller is off.

However the controller may be arranged, the principle involved is that when the motors are revolving by the motion of the car, and the armature connections are reversed as they would be to reverse the direction of motion of the car, the motors begin to generate current as series-wound dynamos. The amount of current generated and the retarding effect will depend on two things—namely, the speed of the car, with the consequent electromotive force in the motors, and the amount of resistance in the circuit. The amount of resistance is regulated by the motorman by means of his electric brake controller. The function of the electric brake controller is to reverse the motors and to insert enough resistance in the circuit to make a comfortable stop. This current in the motors acting as dynamos, in itself acts as a powerful brake to retard the motion of the car. In the General Electric type of electric brake, the current generated in the motors, in addition to having this retarding effect in the motors themselves, is conducted to brake discs that act as magnetic clutches against one of the car wheels on each axle. The car wheel has a disc cast upon it, and against this the magnetic disc acts. The magnetic disc contains a coil which is in series in the brake circuit.

In applying an electric brake of this kind the motorman first puts the controller on a point that inserts considerable resistance in the circuit. When the motors have slowed down, the electromotive force, of course, drops, so that to maintain the same braking current there must be a reduction of the amount of resistance, until, when the car is almost at a standstill, the resistance is nearly all cut out. It might seem at first that the current would die down before the car came to a stop, but it is found that there is enough induction in the motor fields to cause current to flow for a short time after the car has stopped. The residual magnetism in the steel in the fields of the motor is sufficient to cause the motors to begin to generate current when the electric-brake controller is first turned on.

The greatest advantage of an electric brake using motors as generators is in the fact that the braking current instantly falls in value as soon as the wheels begin to slide, and releases the brake until the wheels again revolve. In fact, it is almost impossible to skid the wheels as they are sometimes skidded by being locked by brake shoes. This not only prevents flat wheels but insures a quick stop, because when the wheels are locked and sliding, the braking or retarding power is only about one-third what it was before the wheels began to slide. The electric brake requires extra large motors because of the heating caused by the current generated while braking.

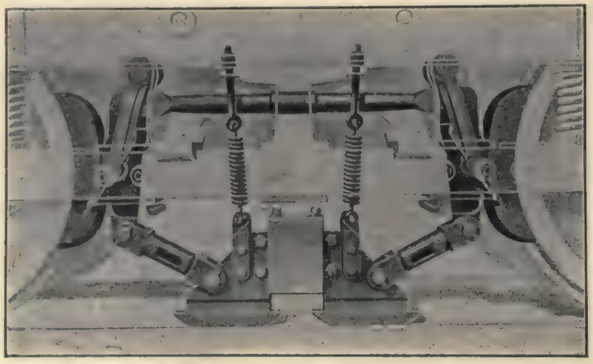
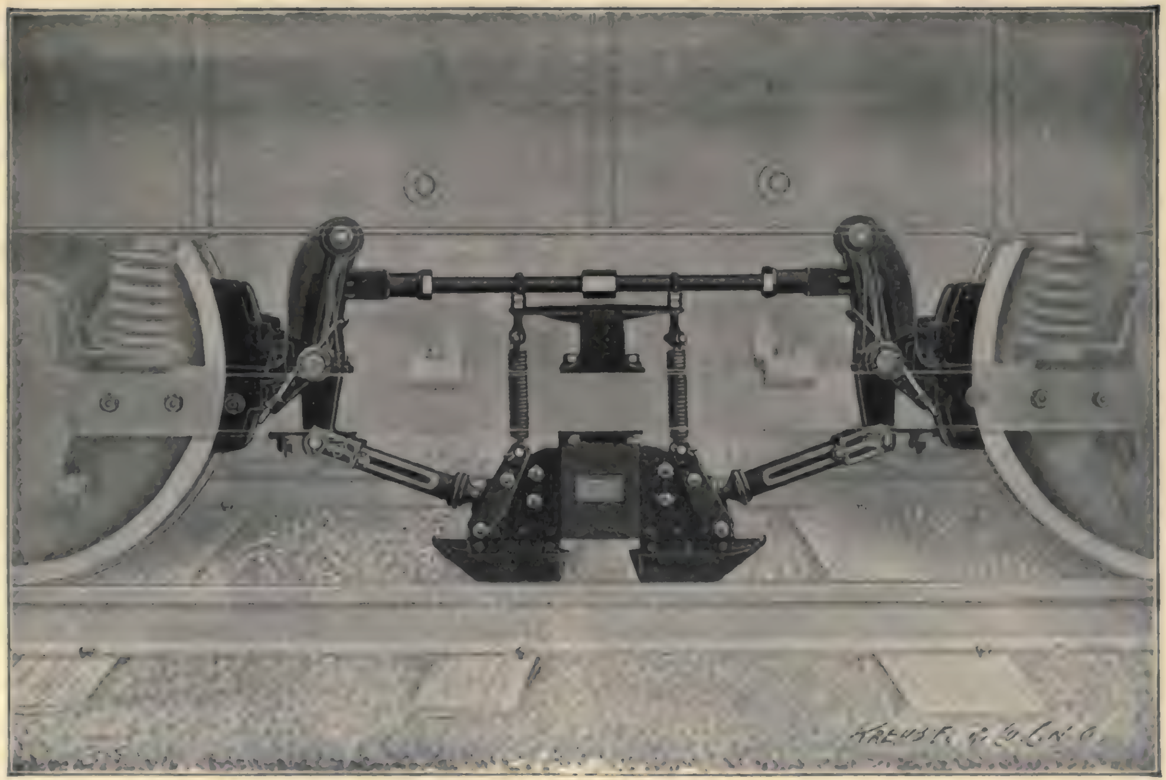


Fig. 56. Magnetic Brake Shoe.

Westinghouse Electromagnetic Brake. The Westinghouse magnetic brake is in principle similar to the General Electric brake as far as the use of motors as generators is concerned; but, instead of assisting the motors by means of a magnetic brake disc acting against the car wheel, a magnetic brake shoe is used (see Fig. 56), which acts against both car wheel and track. This not only retards



MAGNETIC BRAKE SHOWING METHOD OF ATTACHING TO CAR FRAME AND TRUCKS.

Westinghouse Air Brake Co.

through the medium of the wheels but acts directly on the track. It is not dependent upon the coefficient of friction between the wheels and track; and it should, therefore, be possible to stop much more quickly than with any form of brake depending upon the coefficient of friction between the wheels and track.

Track Brakes. Track brakes have been used to some extent on very hilly electric roads. These have a shoe fastened to the truck frame, which acts directly on the track.

Motors as Emergency Brakes. The motors can of course be used to brake the car by simply reversing them if current is applied to them from the line. But in case the trolley flies off or if the circuit breaker or the fuse opens the circuit, or the supply of current is interrupted for any other reason, they may be used as brakes by throwing the reverse lever and moving the controller handle to the multiple position of a two-motor equipment or by simply throwing the reverse lever of a four-motor equipment. These movements throw the motors in multiple and connect the fields and armatures of the motor in such relation that they can generate current. One of the motors then acts similarly to a generator in a power house, deriving its power from the momentum of the moving car instead of from an engine, and sends current through the other motor of the pair which acts like any auxiliary motor trying to revolve its wheels in the opposite direction from that in which they are revolving. The motors of a four-motor equipment are permanently connected in two multiple groups as long as the reverse is not in the central position. In the two motor equipment such connections are not made until the controller handle is turned to the multiple position. As the external resistance is beyond the junction of the two motor circuits, the braking effect is not increased by cutting out the resistance.

The difference in the residual magnetism of the fields or in the magnetic qualities of the fields of the two motors is primarily the cause of the generation of the current. The motors at first act in opposition, but one of them generates the higher voltage and forces a current through the other. This current overcomes the residual magnetism of the second motor, thereby changing its polarity and both motors then act in series to send the current through the low resistance path afforded by the windings. Any current passing increases the strength of the fields and consequently the voltages, so that abnormal currents are generated and the braking action is consequently severe.

This generating action does not take place before the reverse lever is thrown because the connections of the armatures and fields are such that any current generated by reason of the residual magnetism of the fields, flows in such a direction through these that this magnetism is destroyed. The current then ceases to flow. This explains why current is not generated in No. 2 motor with a K type of controller during the change-over period when it is short-circuited, or in equipments when the trolley flies off and the controller is turned on.

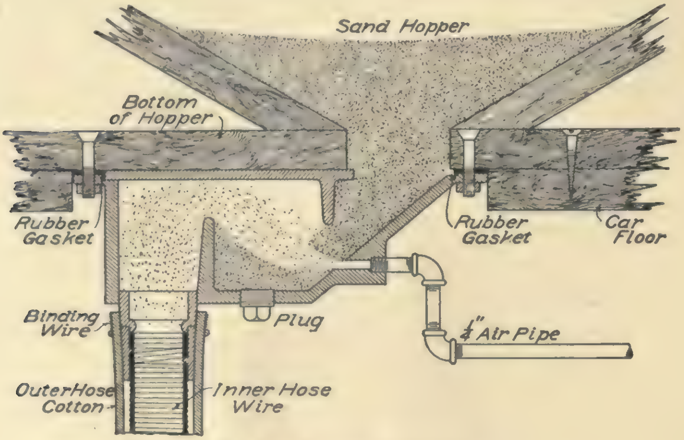


Fig. 57. Pneumatic Sander.

Brake Shoes. The subject of brake shoes is of very little importance on the smaller cars traveling at slow speeds and controlled alone by hand brakes. On the larger high speed interurban cars, the brake shoe question becomes an important item because of the rapidity with which they are worn away. On such cars shoes sometimes last but about one week. This means eight shoes per week per car or an expense of about $4.00 per car per week.

Brake shoes are usually of soft gray cast iron with inserts of steel, although some companies use very hard iron. They are usually fastened by means of a key to a brake shoe head permanently attached to the brake rigging. The brake levers are so adjusted that the shoes clear the wheels about $\frac{3}{16}$-inch when the brakes are released. This distance increases as the shoes wear, so that the brakes must be adjusted frequently to take up the slack and prevent waste of air.

Track Sanders. A sprinkling of sand on the rail increases wonderfully the adhesion of the rail and wheel. There is usually on cars some provision made for scattering sand on the rails immediately in front of the leading wheels. From sand boxes placed under the seats in the smaller cars, or on the truck of the larger ones, flexible hose or pipes drop within an inch or two of the rail in front of the leading wheels. A valve under the control of the motorman regulates the flow of sand to the rail. Sometimes air pressure is used to blow the sand out of the sand box into the hose. In this case air pressure is obtained from the air brake system, and an air valve leading to the sand box is placed in the motorman's cab. A section through a pneumatic sander of this kind is shown in Fig. 57.

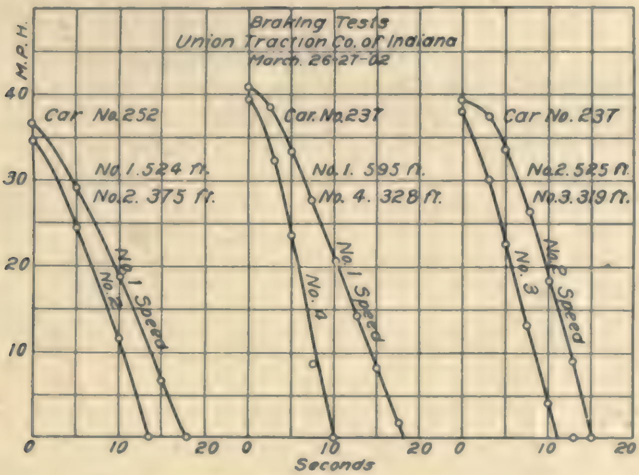


Fig. 58. Curves of Braking Tests.

Coefficient of Friction. It has been found by experiment that the coefficient of friction between the car wheel and rail is about 25 per cent of the weight on the wheel when the rails are dry; that is, a car wheel having a weight of 2,000 pounds upon it would not be able to exert either an accelerating or a retarding force exceeding 25 per cent of this, or 500 pounds. This is when the wheel is rolling. There is apparently a kind of locking or inter-meshing of the rough surfaces of wheel and rail when the wheel is rolling, because it is found that when a wheel begins to skid or slide, the coefficient of friction falls off about two-thirds. The maximum braking or retarding force that can be obtained, therefore, in a dry rail, amounts to 25 per cent of the weight of the car. If the rail is slippery this is much reduced; or if the wheels are allowed to slide it is also much reduced. If more retarding force than can be obtained through the medium of a wheel rolling on the rail is desired, it must be obtained either by the track brakes or by magnetism.

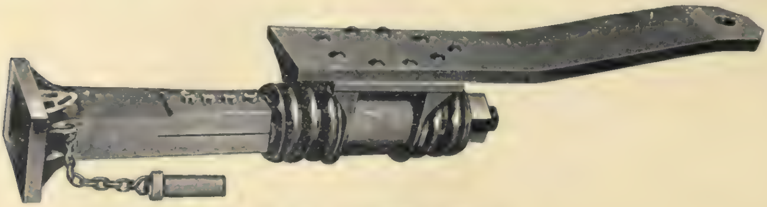


Fig. 59. Automatic Coupler.

Rate of Retardation in Braking. The rate of retardation of cars in braking is usually 1 to 2 miles per hour per second. In other words a car going at a speed of 40 miles an hour will usually be stopped in 40 to 20 seconds.

The plotted results of some braking tests (Fig. 58) show a higher rate of acceleration. These tests were made on an interurban car weighing about 63,000 pounds, equipped with straight air brakes. Of the six curves shown, that giving the highest rate of retardation is No. 4. This shows a stop from a speed of 38 miles per hour in 9½ seconds or a rate of retardation of about 4 miles per hour per second. All of the curves shown are for emergency stops. They show about the highest rate of retardation that could be made with the equipment.

Drawbars and Couplers. For small surface cars a crude drawbar is usually provided consisting simply of a straight iron bar pivoted under the car and provided with a cast-iron pocket near the end. A coupling pin passing through the pocket of one coupler and through a hole in the end of the bar of the other, holds the two cars together.

The requirements of a coupler for heavier cars such as those used on interurban and elevated roads are more exacting. The ends of the bars are usually pivoted under the car about five feet back from the bumper. A spring cushion intervenes between the pivot point and the drawbar head. The illustrations, Figs. 59 and 60, show the action of the Van Dorn Automatic coupler, which is the one used by all the elevated lines in the United States. The link is placed in one of the drawbar heads and the pin in the other. As the cars come together the wedge-shaped end of the link forces its way between the pin and a spring. When the faces of the drawbar heads meet, the spring forces the link to engage the pin. The mechanism is designed especially to prevent lost motion between coupler heads because, unlike steam railroad drawbars, electric car drawbars must swivel to round curves and a great amount of play at the point of coupling with swiveling drawbars would allow the couplers to bend under a pushing strain.

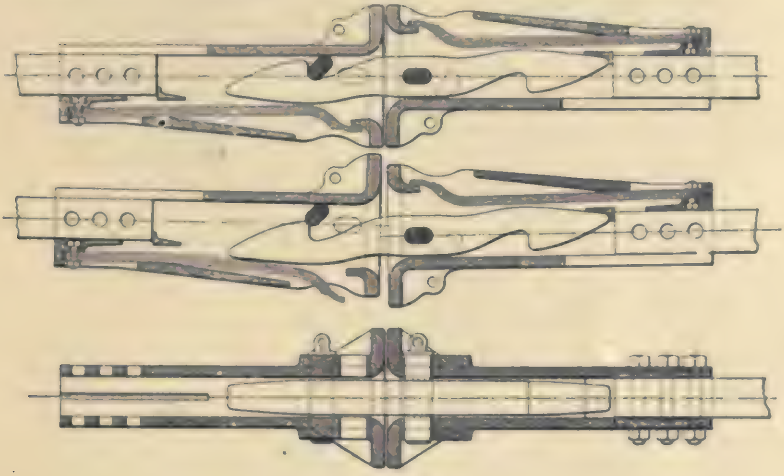


Fig. 60.

CAR CONSTRUCTION.

Car Bodies. In cities there are three general types in common use; namely, box cars, suited for winter use only; open cars, suited for summer use only; and semi-convertible cars, which can be adapted to either summer or winter use. The open and box cars are the older types. The semi-convertible car is usually provided with a center aisle, and cross seats on each side of this aisle.

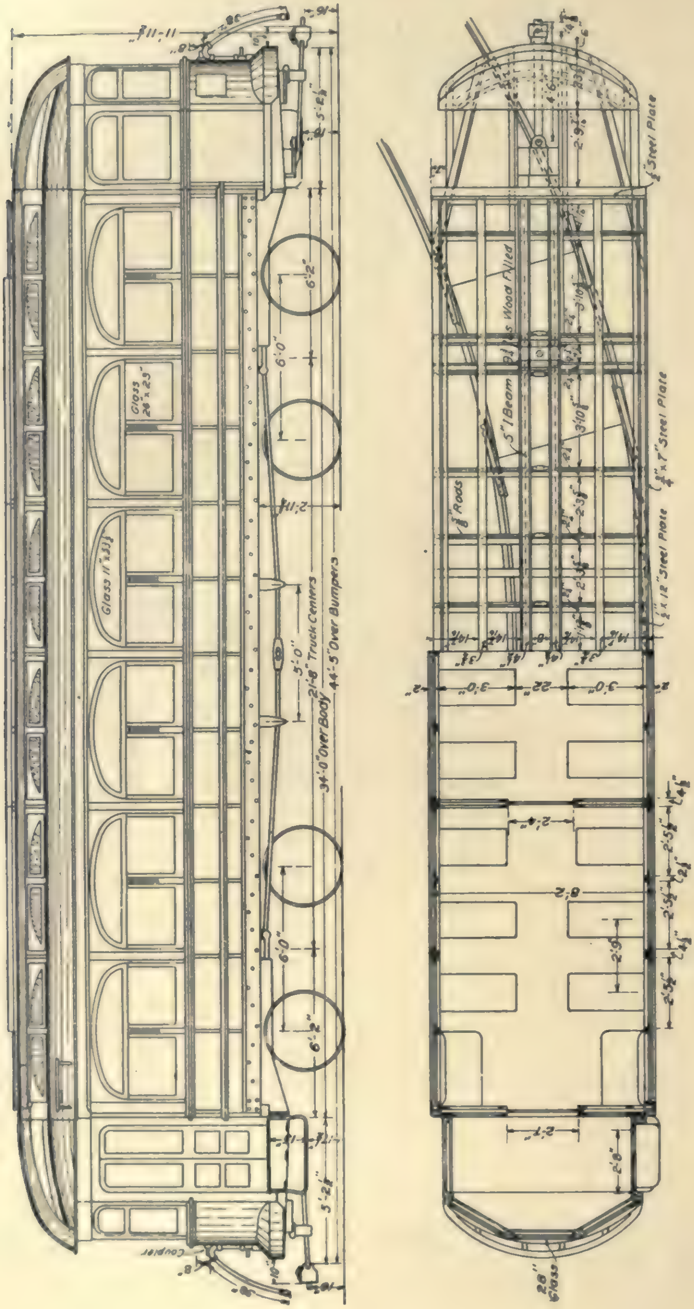


Fig. 61. Side Elevation and Plan of Car.

The windows are large, so that they can be lowered or raised in summer to make something approaching the character of an open car. The car bottom, which forms the basis for the entire car structure, is constructed with longitudinal sills either of steel or of wood combined with steel. One form of construction employs as the main supports two steel channel bars extending the full length of the car. Steel I-beams are sometimes used. Where wood is used in combination with steel for longitudinal sills, the steel is usually in the form of flat steel plates between the timbers. Most cars seat about one passenger per foot of length over all.

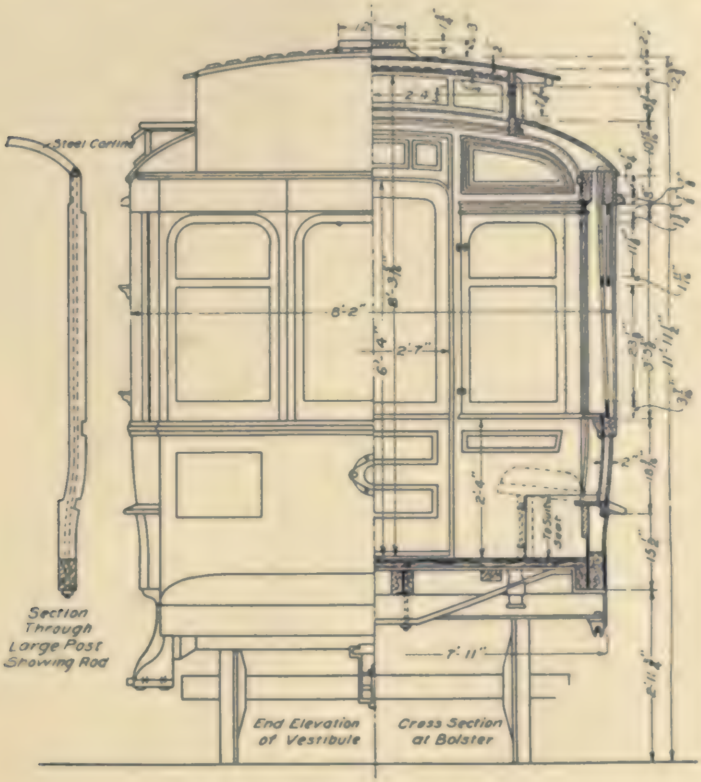


Fig. 62. Cross-Section of Car Body.

Many more difficulties are met in the construction of passenger cars for electric railways than in steam coach construction. The electric car must have low steps and platforms and turn short curves.

The difficulties are largely in the floor framing of the car. The platforms at each end are usually eight to ten inches lower than the floor of the interior. As the car must frequently be designed to pass around curves of small radius, often of only thirty or forty feet, sufficient clearance must be provided for the swing of the trucks. This necessitates that the trucks of a double truck car be set far enough back towards the center of the car to clear the dropped platform timbers, shown in Fig. 63. In the illustration shown, Fig. 61, the truck centers are but 21 feet 8 inches apart, while the ends overhang the truck centers 11 feet 4½ inches. It is difficult to support this overhanging weight properly. The difficulty is increased by the fact that the rear platform is often crowded with passengers having an aggregate weight of one ton or more. Trusses manifestly cannot be employed to give rigidity to the long platform. This is usually given in cars of wood construction by reinforcing the platform timbers with steel plates as shown in the figure. In order that the dropping tendency of the platform shall not bow up the body of the car between the trucks this portion must be braced rigidly. The space below the windows and above the side sill is utilized for this purpose. The side sill is moreover strengthened by having steel plates bolted to it.

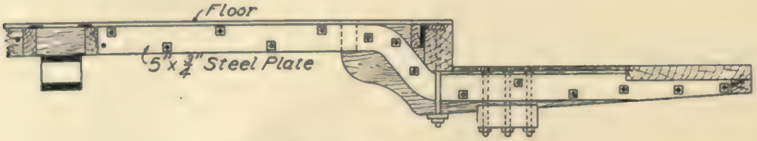


Fig. 63. Reinforcing Plates.

The longitudinal members of the body framing are termed sills. These are usually of long leaf yellow pine. Various combinations of wood and steel are employed for sills, an example of which is seen in Figs. 61 and 62. The sills are kept the proper distance apart by "bridgings" or cross sills mortised into them at intervals and by "end sills." The whole framing is tied together by the rods running parallel to the bridging. These tie rods are often provided with turn buckles for tightening when occasion may require.

The outer sills are termed side sills; those nearest the center of the car, the center sills or draft timbers; while those between are called intermediate timbers.

The remaining portion of the car is constructed much after the manner of a steam coach. The posts between the windows are mortised into the side sill at the bottom and into a top sill at their upper end. They are laterally braced by a belt rail immediately under the window opening, both the belt rail and the posts being gained out so that the rail fits flush with the posts. A wide letter board gained into the post just below the side plate adds to the bracing of the side of the car, as does also an iron truss usually one-fourth to one-half inch thick and two to three inches wide which is gained into the posts on the inside running just under the windows between the truck centers, and then descends to pass through the side sills and fasten by a bolt underneath.

The roof consists of the upper and lower decks. That portion over the platform or vestibule is termed the hood. Rigidity is given to the whole upper portion of the car by the end plates resting on the corner posts and extending between the side plates at either end of the car body proper, and by steel carlins which conform to the peculiar shape of the roof and extend between the side plates. The steel carlins are usually placed over alternate side posts. Bolted on either side of them and placed at intervals of about twelve inches between are wood carlins. The wood carlins of the lower deck extend from the side plate, to which they are fastened by screws, to the top sill, which is immediately below the windows of the upper deck. Above these windows is the top plate, supporting the carlins of the upper deck, which extend between and a few inches beyond the two top plates. Poplar sheathing three-eighths or one-half inch is nailed over carlins and on this heavy canvas usually of six or eight ounce duck is stretched tightly. Several coats of heavy paint on the canvas and a trolley board for supporting the trolley stand complete the roof. On the underside of the carlins the headlining, usually of birch or birdseye maple, is secured. This forms the interior finish of the ceiling of the car.

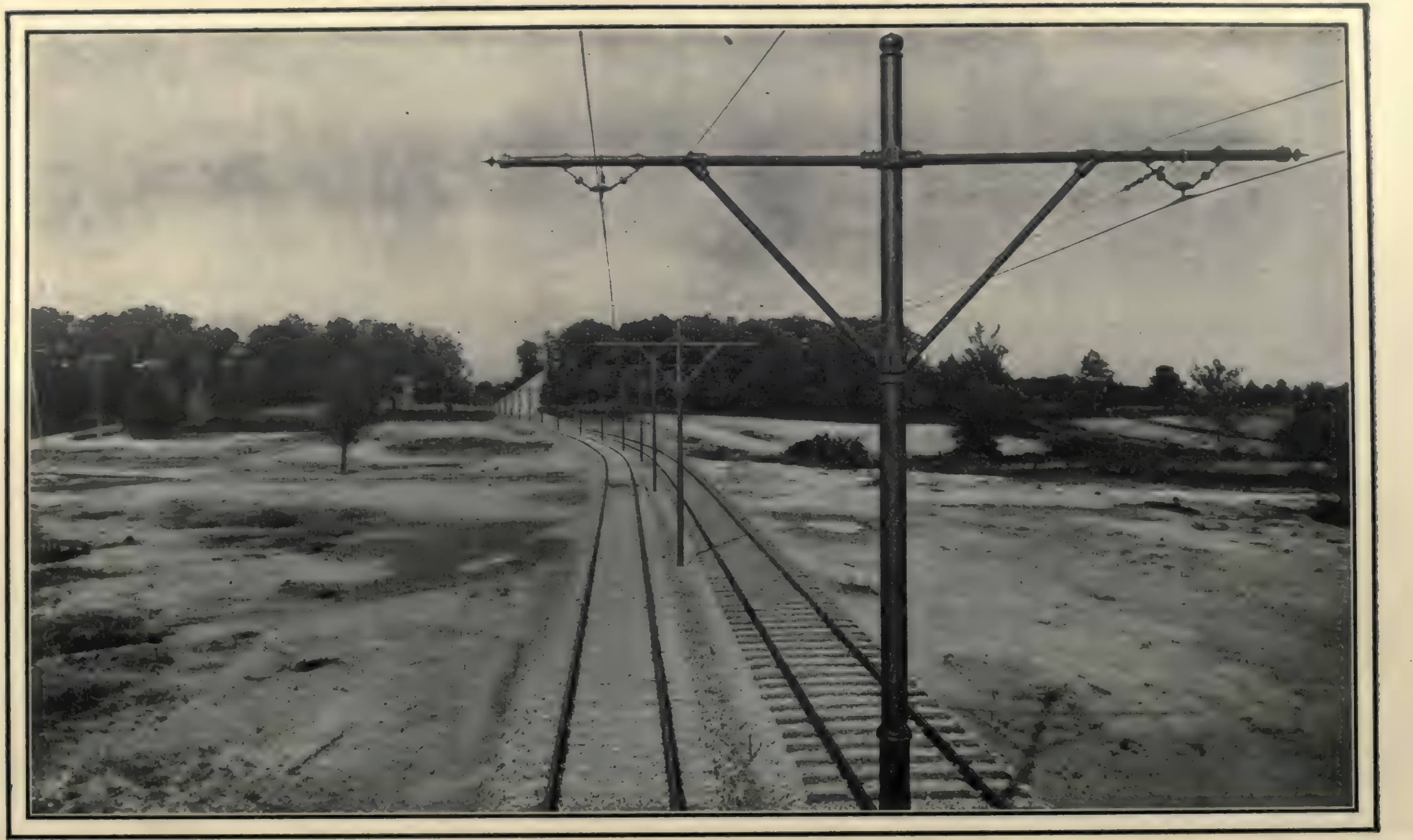
Steel Car Framing. As a result of the demands of the officials of the New York Subway for cars of greater strength and less subject to danger from fire, much progress has been made in the last few years in the construction of cars with steel framing. Steel construction is much more expensive than that in which the framing is of wood and is considerably heavier. The advantages lie partly in the fact that it is more durable, but the great reason for the interest with which the new style of construction has been received is that the danger of collapse and consequent injury to passengers, in case of accident, is greatly diminished.

Car Weights. The total weight of a street car with a body 16 feet long over corner posts mounted on a single truck with two motors is approximately 14,000 pounds. Of this the body weighs about 4,500 pounds, the truck 4,400 pounds, and the motors and the electrical equipment the remaining 5,100 pounds. The weights of the separate parts of a certain interurban car measuring 52 feet 6 inches over the bumpers mounted on double trucks, one of which carried two motors, is body 34,065, motor truck 9,565, trail truck 6.670, electrical equipment 12,800; total 63,100.

An interurban car of about the same size as the one just mentioned but equipped with four motors gave the following weights: Body with controller and resistance grids 39,000 pounds, trucks 19,130 pounds, motors 15,420 pounds; total 73,550 pounds.

Car Painting. A great deal of attention is given to the proper painting of cars. A car painted with care and proper materials always presents an attractive appearance, while one carelessly painted is readily noticeable. New cars go through an elaborate painting process. The time required is from two to three weeks. The following scheme may be regarded as an example of a good process:

A coat of primer is given the car the first day. On the third day all irregularities are puttied up smooth. On the fourth and fifth days a heavy primer is applied, one coat on each day. A coat of filler is given on the sixth day and allowed to harden the following day. The next paint applied is termed a guide coat. This is of a color different from the preceding ones and serves as a guide for the rubbers, who on the following day go over the car with mineral wool, fine sandpaper, or pumice stone and rub it until the guide coat is worn away. This assures an even and smooth surface. On the tenth day the car is allowed to stand. A coat of the color desired is applied, one on each of the following three days. On the fourteenth and fifteenth days the car is striped with the desired ornaments and lettered. This is usually done in aluminum or gold leaf. The car is then given three coats of varnish on alternate days, and the work is completed. The best practice brings the cars in once each year to be revarnished.



TYPICAL HIGH GRADE TRACK CONSTRUCTION.

J. G. White & Co.

ELECTRIC RAILWAYS.

PART II.

OVERHEAD CONSTRUCTION.

Trolley Wire. The trolley wire is suspended from the span wires or brackets in such a way as to permit of an uninterrupted passage of an upward pressing trolley wheel underneath it. The trolley wire itself may be either round, grooved, or figure 8 in section. Where a round wire is used, No. 00 B. & S. gauge is the most common size. Figure 8 wire, so called from its section, which is shown in Fig. 64, is designed to present a smooth under surface to the trolley wheel, which will not be interrupted by the clamps or ears used to support it. Clamps are fastened to the upper part of the figure 8. The grooved wire is rolled with grooves into which the supporting clamps fasten. This wire also presents a smooth under surface to the trolley wheel.

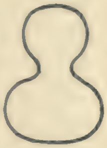


Fig. 64.

Trolley-Wire Clamps and Ears. The trolley is supported either by clamps or by soldered ears. One type of clamp grasps the wire by virtue of screw pressure. A soldered ear is shown at E, Fig. 65. This ear has small projections at each end, which are bent around the wire to assist the solder in holding the wire to the ear. Another form of ear, used to some extent, holds the wire by virtue of having the edges of the groove offset or riveted around the wire.

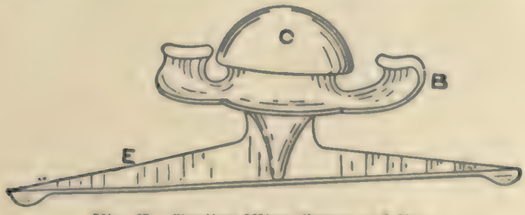


Fig. 65. Trolley Wire Clamp and Ear.

The ear or clamp screws to a bolt which is insulated from the metal ear through which passes the span wire. A cross-section through a common type of trolley-wire hanger is shown in Fig. 66. Here there is an outer shell of metal, which is adapted to hook to the span wire. In this shell is an insulating bolt, that is, a bolt surrounded with some form of insulating material which is very strong mechanically and not likely to be cracked by the hammering action of the passing trolley wheel. Most of the insulating compounds used in making trolley-wire insulators are trade secrets. Another kind of insulator called the "cap and cone" type is shown at C, Fig. 65. In these insulators, the metal part B which fastens to the span wire does not completely surround the insulation C. Wood has sometimes been used for the insulation of trolley-wire hangers.

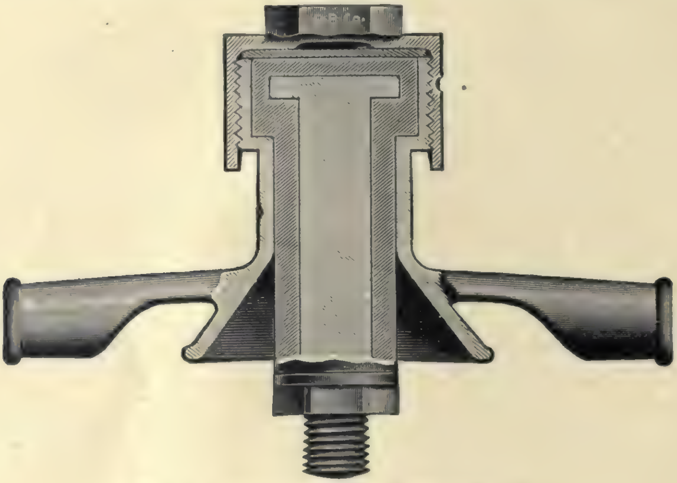


Fig. 66. Cross-Section Trolley Wire Hanger.

Span Wires. In city streets, the trolley wire is commonly suspended from span wires stretched between poles located on both sides of the street. These span wires are of $\frac{1}{4}$-inch or $\frac{3}{8}$-inch galvanized stranded steel cable. In order to add to the insulation between the trolley wire and the poles at the side of the street, what is called a *strain insulator* is placed in the span wire. This is an insulator adapted to withstand the great tension put upon it by the span wire. One of these is shown in Fig. 67. Means are usually provided for tightening the span wires as they stretch and as the poles give under the strain. The insulator in Fig. 67 has a screw eye for that purpose.

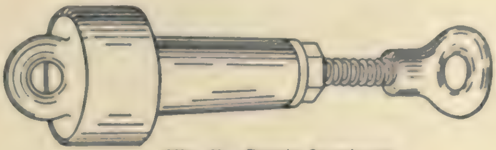


Fig. 67. Strain Insulator.

Brackets. In the bracket type of overhead construction, a trolley wire is fastened to brackets placed on poles near the track. This construction is used on suburban and interurban lines where the presence of poles near the track is not objectionable. It has been found that a rigid connection of the trolley wire to a bracket is likely to result in the breaking of the trolley-wire insulators. For this reason the brackets now commonly used provide for a flexible suspension of the trolley-wire hanger from the bracket. A bracket employing such flexible construction, made by the Ohio Brass Company, is illustrated in Fig. 68.

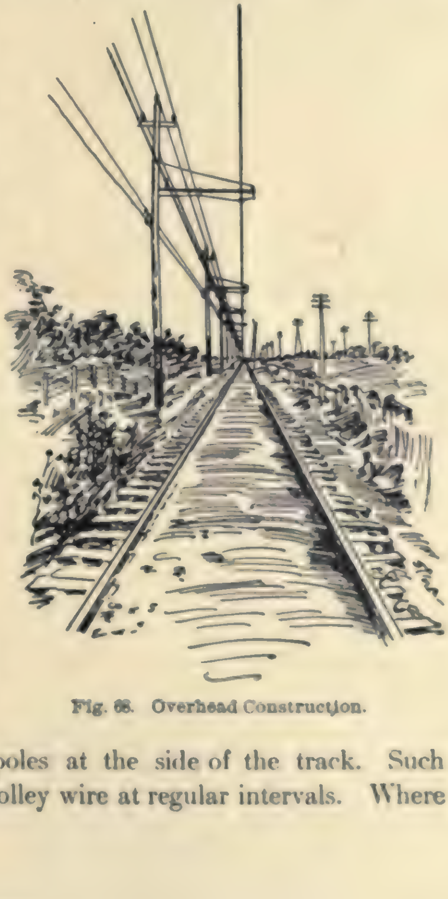
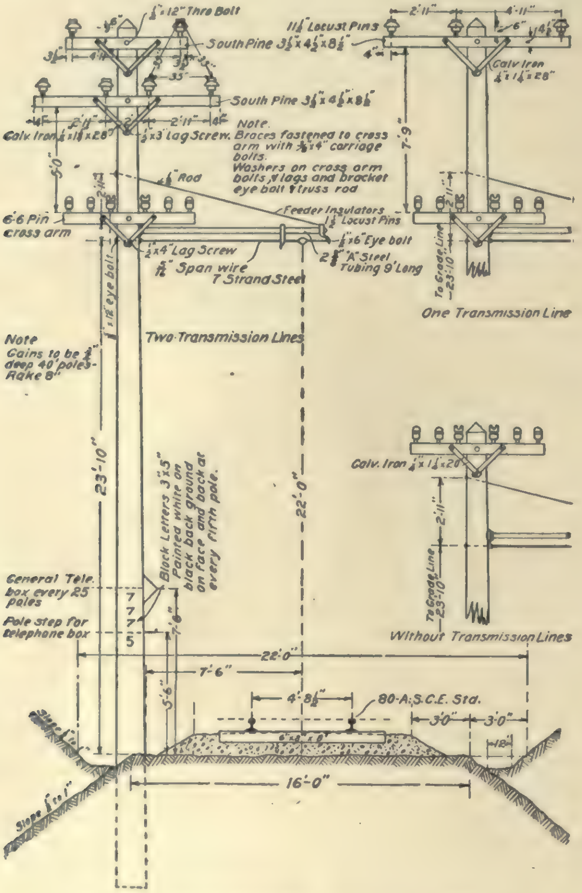


Fig. 68. Overhead Construction.

An example of standard straight-line bracket construction is shown in Fig. 69.

Feeders. Where additional conductivity is needed beyond that furnished by the trolley wire itself, feeders are run on insulators along the poles at the side of the track. Such feeders are connected to the trolley wire at regular intervals. Where span-wire construction is used, the feed wire may be substituted for the span wire at the pole where the connection between feed wire and trolley wire is made. In such a case, of course, a trolley-wire hanger is used which has no insulator, so that the current feeds directly through the hanger. Another method is to run the feed connection parallel with a span wire and a short distance from it.



1/2"×12" Thro Bolt
South Pine 3 1/2"×4 1/2"×8 1/2"
South Pine 3 1/2"×4 1/2"×8 1/2"
35"
2'-11"
2'-11"
Galv. Iron 1/4"×1 1/4"×28"
1/2"×3" Lag Screw.
Note. Braces fastened to cross arm with 3/8"×4" carriage bolts. Washers on cross arm bolts, lags and bracket eye bolt & truss rod
5'-0"
1/2" Rod
6-6 Pin cross arm
Feeder Insulators 1 1/2" Locust Pins
1/2"×6" Eye bolt
1/2"×4" Lag Screw
5/16" Span wire 7 Strand Steel
2 1/2" "A" Steel Tubing 9' Long
1/2"×12" eye bolt
Two Transmission Lines
Note Gains to be 1/2" deep 40' poles - Rake 8"
23'-10"
Block Letters 3"×5" Painted white on black back ground on face and back at every fifth pole.
22'-0"
General Tele. box every 25 poles
7
7
7
5
Pole step for telephone box
7'-6"
5'-6"
22'-0"
7'-6"
4'-8 1/2"
80-A.S.C.E. Std.
6"×8"×8'
3'-0"
3'-0"
18"
16'-0"
Slope 1 to 1
Slope 1 to 1
11 1/2" Locust Pins
2'-11"
4'-11"
6"
4 1/2"
4"
Galv. Iron 1/4"×1 1/4"×28"
7'-9"
2'-11"
To Grade Line 23'-10"
One Transmission Line
Galv. Iron 1/4"×1 1/4"×28"
2'-11"
To Grade Line 23'-10"
Without Transmission Lines

Fig. 69. Standard Straight Line Construction.

Section Insulators. Section insulators are usually placed in the trolley wire at regular intervals. Such a section insulator is shown in Fig. 70. Its purpose is to insulate one section of trolley wire from the next, so that in case the trolley wire of one section breaks, or is grounded in any other manner, that section can be disconnected and the other sections on either side kept in operation. In large city street-railway systems, each section of trolley wire usually has its own feeder or feeders, independent of the other sections. This feeder is supplied through an automatic circuit breaker at the power house. In case a certain section of trolley wire is grounded the large current that immediately flows will open the circuit breaker supplying that section; but, unless the ground contact is of an extremely low resistance, it will not affect the operation of the other feeders. Should it be of sufficiently low resistance to cause all the generator circuit breakers to open, it would, of course, interrupt the entire service temporarily; but usually the circuit breaker on any individual feeder will cut that feeder out before all the circuit breakers will open.

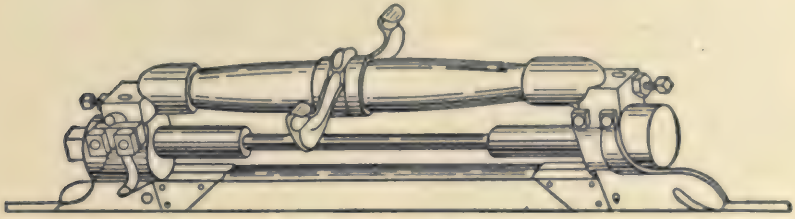


Fig. 70. Section Insulator.

High-Tension Lines. Where high-tension alternating-current wires are run, as in the case where the road is of such length as to require the establishment of several substations, these high-tension circuits are usually carried some distance above the 500-volt direct-current trolley and feeders. An example of interurban overhead construction is shown in Fig. 69. Here the high-tension wires are carried on large porcelain insulators of a size necessary for 26,000 volts. These insulators are placed 35 inches apart. High-tension wires are kept so far apart because of the danger that arcs will in some way be started between the lines, as the high-tension current will maintain an extremely long arc. The blowing of green twigs across the lines, or birds of sufficient size flying into the lines, is likely to establish arcs which will temporarily short-circuit the line. The greater the distance apart of the wires, the less danger that such things will occur.

Both glass and porcelain insulators are successfully used on lines of very high tension. Glass is the cheaper and porcelain has the greater mechanical strength.

High-tension wires are usually of hard-drawn copper or of aluminum made up in the form of a cable of several strands. Aluminum is lighter for a given conductivity than copper; and, at the market price controlling at the present time, is cheaper. It is, however, more subject to unevenness of composition, which leaves weak spots at certain points in the wire; and that is the reason why aluminum is now always used in the form of a stranded cable rather than as a single conductor. Aluminum, being considerably softer than copper and melting at a lower temperature, is more likely to be worn through as a result of abrasions or to be melted off by a temporary arc. These slight objections are balanced against its smaller first cost as compared with the cost of copper.

The calculation of the proper amount of feed wire for a given section of road is somewhat similar to the calculation of electric light and power wiring as already outlined. It is first necessary to estimate approximately the amount of current required at different portions of the line. The amount of drop to be allowed between the power house and cars must be decided arbitrarily by the engineer. A drop of 10 per cent is probably the one most commonly figured upon in designing feeding systems. The resistance in ohms of the copper feeders required to conduct a given current with a given loss in volts, can be calculated by dividing the volts lost by the current, according to Ohm's law. By the aid of a table which gives the conductivity of various sizes of wire according to the methods outlined in connection with "Electric Wiring," the proper number and size of the feeders can be determined. The most difficult thing to determine is the load that will be placed upon any section of the line. Of course, there will be times when cars are bunched together owing to blockades. It is out of the question to provide enough feeder copper to keep the loss in voltage within reasonable limits at such times. The ordinary load upon any feeder is used as the basis of calculation in most cases. The amount of current required per car depends on the weight of the car and the character of the service. This will be taken up later under the head of "Operation."

THIRD RAIL.

Location. The third-rail system of conducting current to electric cars, as most commonly employed in the United States, follows the example set by the Metropolitan West Side Elevated Railway of Chicago. All the elevated roads in the United States are now operated by means of third rails located at one side of the track. The third rail is an ordinary T-rail and is located with the center of its head 20 inches outside of the gauge line of the nearest track rail, and $6\frac{3}{16}$ inches above the top of the track rail. On a few interurban roads this distance has been increased in order to accommodate certain steam railroad rolling stock which must at times be operated over the line.

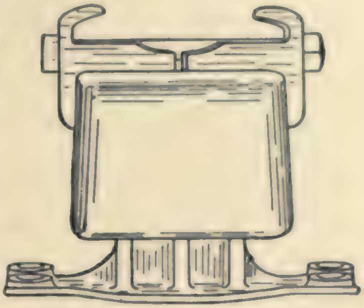


Fig. 71. Third-Rail Insulator.

Insulators. The third rail is supported every fifth tie on an insulator. These insulators on first construction were made of wooden blocks boiled in paraffine, but at the present time more substantial forms of insulation are being used.

One form of third-rail insulator, known as the "Gonzenbach," has a base of cast iron resting on the tie. Over this is placed a cap of insulating material similar to that used in strain and trolley-wire insulators. Over this insulating material is another cast-iron cap upon which the third rail rests. The weight of the third rail holds it in position, and there is no clamping together of the various parts of the insulator.

Another form of third-rail insulator is made of what is called "reconstructed granite," and another of vitrified clay. Fig. 71 shows one of the latter.

Switches. Where the third rail is used, a contact shoe is placed on each side of both trucks of the motor car. At switches it is necessary to omit the third rail for a short distance on one side of the track, and place a short section of third rail on the other side of the track so that the current supply to the car will be uninterrupted.

At Highway Crossings. Where the third-rail system is employed on interurban surface lines, it is necessary to omit a section of it at every highway crossing. If the crossing is too wide to be bridged across by a car, the car must have sufficient momentum to drift over such crossings when it comes to them. To connect across the break in the third rail at such points, an underground cable is generally used. This cable must be thoroughly protected against leakage of moisture into the insulation where it comes to the surface for connection to the third rail.

Another form of third rail, laid several years ago on some of the lines of the New York, New Haven & Hartford Railroad, was of an inverted V-shape, and was laid midway between the track rails with its top 1 inch above them and its bottom only 1⅝ inches above the ties. It was supported on wooden blocks. This location of the third rail has never been popular, because of the poor insulation with the rail located so close to the ties between the rails.

Conductivity. The conductivity of a steel rail varies considerably. A rail of the ordinary composition used on steam railroads is too high in carbon to give the best conductivity. Such a rail has about one-tenth the conductivity of the same cross-section of copper. Steel can easily be obtained, however, which will have one-seventh the conductivity of copper, and the additional cost of obtaining such special steel is quite low, so that the majority of roads installing the third-rail system have seen fit to pay the extra cost and thereby secure a softer rail than that usually employed in track rails.

Cost. The cost of the third-rail system is less than an overhead trolley system, provided enough copper is placed in the trolley feeders to make the conductivity of the trolley system equal to that of the third-rail system. It is very seldom, however, that a trolley system is so constructed on an interurban road; and hence the trolley system, as usually constructed, is cheaper than the third-rail system, because it is not of equal conductivity to a third-rail system.

Advantages in Operation. Where very heavy cars or trains are to be operated, the third-rail system is decidedly an advantage, for two reasons In the first place, it affords the cheaper method of conducting a given heavy volume of current; and in the second place, the contact shoes that conduct the current from the third rail to the moving car or train are built to carry a much larger volume of current than the trolley wheel, which has only a small area of contact on the trolley wire. Ordinarily there are two of these contact shoes in multiple for every motor car.

Another advantage of the third rail over the trolley is that the trolley may leave the wire at high speeds or in passing switches. On well-constructed roads, where the trolley wire is kept in good alignment and the track is smooth, there is little trouble from this source; but it is undoubtedly a convenience to be able to operate cars or trains without giving any attention to a trolley pole.

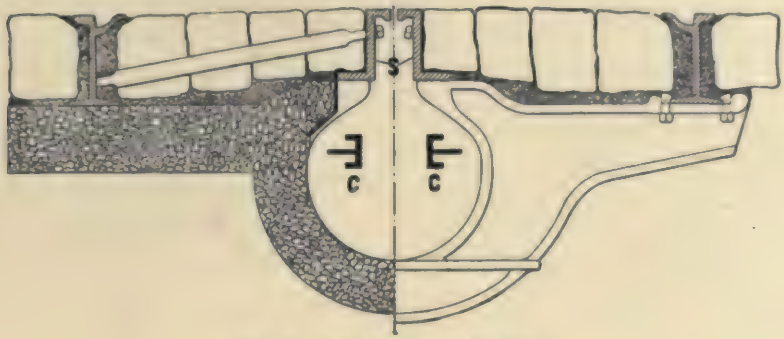


Fig. 72. Cross-Section of Conduit.

CONDUIT SYSTEMS.

The underground conduit system, in which the conductors conveying the current to the cars are located in a conduit under the tracks, is in use in two cities of the United States—New York City and Washington, D. C. The cost of this system, and the danger of interruption of the service where the drainage is not excellent, have prevented its more extensive adoption.

The New York type of conduit is a good example of this construction. The conductors consist of T-bars (CC) of steel supported from porcelain cup insulators located 15 feet apart in the conduit. A cross-section of the conduit is shown in Fig. 72. At each insulator a handhole is provided (Fig. 73), so that access may be had to the insulator from the street surface. Manholes are provided at intervals of about 150 feet, so that the dirt which collects in the conduit can be scraped into these manholes and removed at intervals. The manholes also serve as points of drainage to the sewer system.

Contact Plow. Current is conducted to the car through a pair of contact shoes commonly called a *plow* (Fig. 74). This plow has the two shoes insulated from each other, and from the frame of the plow. They are provided with flat springs that hold the shoes against the conducting bars in the conduit. The shank of the plow is thin enough ($\frac{9}{16}$ inch) to enter the slot of the conduit. The conductors pass up through the middle. These plows can, of course, be removed only when the car is over an open pit.

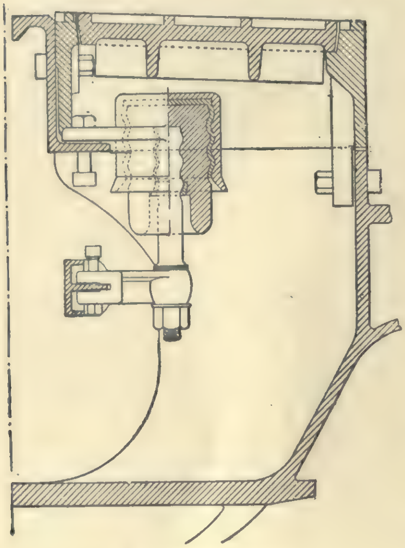


Fig. 73. Handhole.

Cost. A conduit system of this kind is very expensive to build because of the fact that a very deep excavation must be made in the street to accommodate the conduit. The track rails, slot rails, and sheet-steel conduit lining are held in alignment by cast-iron yokes placed 5 feet apart. The entire space around and underneath these yokes is filled with concrete in order to give rigidity and a permanent track. Three expensive items, therefore, enter into the construction of a conduit road—namely, the deep excavation, which may call for the changing of other underground pipes or conduits in the street; the large amount of iron and steel needed for the yokes and slot rails; and the large amount of concrete needed.

On American conduit roads the slot and conduit are placed under the middle of the track. Some of these roads are simply reconstructed cable-conduit roads in which the old cable conduit has been used for electrical conductors. In the conduit road at Buda-Pest, Hungary, the slot is placed alongside one of the track rails.

Current Leakage. The leakage on an underground conduit road is considerable, because the insulators are necessarily located in a damp, dirty place, which causes leakage over the surface of the insulators. This leakage, however, is not prohibitive so long as the conductor rails are not under water. If on account of poor drainage the conductor rails become submerged, the leakage becomes so great that it is impossible to operate the road.

It will be noticed that the conduit system as illustrated here employs two conductor rails—one for the positive side of the circuit and the other for the negative. The track rails, therefore, are not used as conductors, and one side of the circuit is not grounded as in the ordinary trolley system, although the leakage to ground may be considerable from one or both conductor rails.

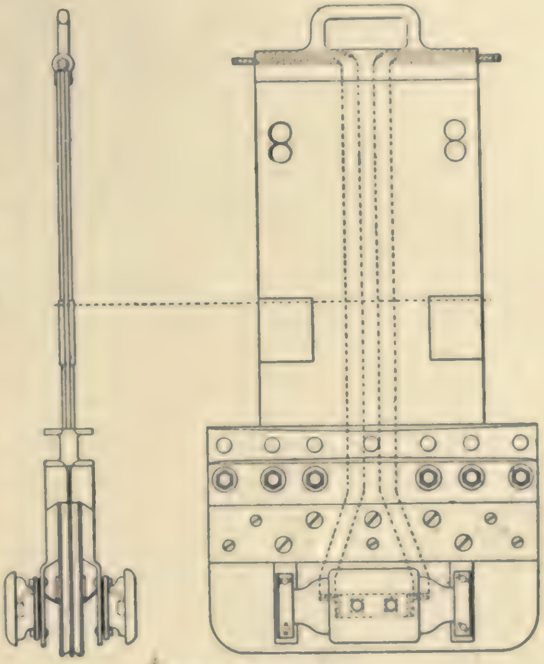


Fig. 74. Contact Plow.

TRACK CONSTRUCTION.

Girder Rail. A great variety of track rails are used in electric railways. The most common at one time was the girder, a typical section of which, with joint, is illustrated in Fig. 75. This is an outgrowth of the old tram rail used on horse railways. It has a tram alongside of the head, on which vehicles may be driven. Its chief advantage from the standpoint of the railway company is that there is plenty of room for dirt and snow to be pushed away by the flanges of the cars. If the company maintains the paving, it may be to its advantage to have teams use the steel track rather than the paving, although this advantage in maintenance is probably more than compensated for by the delay of cars through the regular use of the track by teams.

Trilby Groove Rail. A modification of the girder rail, known as the *Trilby*, and sometimes as the *grooved girder*, is shown in Fig. 76. A rail similar to this is used in several large cities of the United States. It has a groove of such a shape that the flanges of the car wheels will force snow and dirt out of it instead of packing it into the bottom of the groove, as in the case of the regular European narrow-grooved rail. A narrow-grooved rail in which the grooves correspond closely to the shape of the car-wheel flanges is sure to make trouble in localities where there is snow and ice, as the grooves become packed and derail the cars.

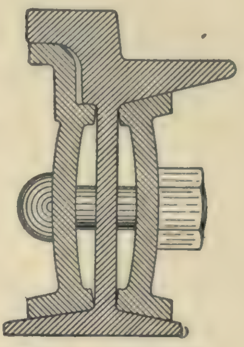
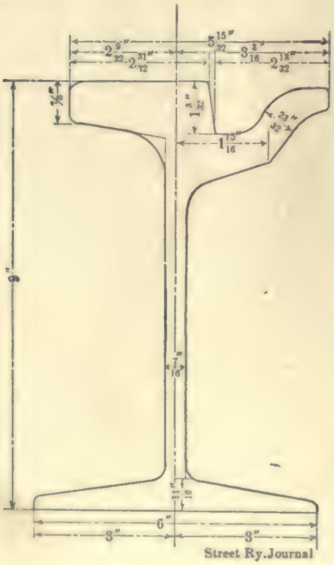


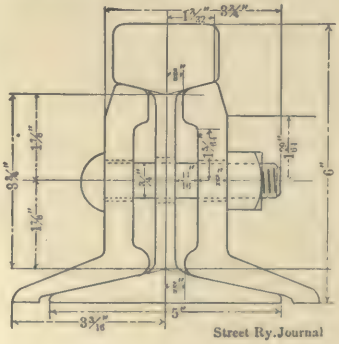
Fig. 75. Girder Rail.

Shanghai T-Rail. In some systems a T-rail is used. Where the T-rail is to be used with paving, the popular form is the Shanghai T, shown in Fig. 77. This rail is high enough to permit the use of high paving blocks around it.



Street Ry.Journal

Fig. 76. Grooved Rail.

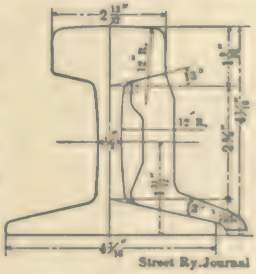


Street Ry.Journal

Fig. 77 Shanghai T-Rail and Joint.

Common T-Rail. The T-rail used by steam railroads is known as the A. S. C. E. standard T-rail, because it follows the standard dimensions recommended for T-rails by the American Society of Civil Engineers. A standard 65-pound T-rail of this kind is shown in Fig. 78. Other weights of this rail have the same relative proportions. Such a rail is used for interurban roads, and for suburban lines in streets where there is no block paving. The high rails are used to facilitate paving with high paving blocks.

Track Support. The greater portion of track is laid on wooden ties. These ties, in the most substantial wooden tie construction, are 6 inches by 8 inches in section, and 8 feet long. They are spaced two feet between centers. Sometimes smaller ties, spaced farther apart, are used in cheaper forms of construction; but the foregoing figures are those of the best construction known in American railway practice. In paved streets, ties are usually employed, although sometimes what is known as "concrete stringer" construction is used instead of ties to support the rails. A strip of concrete about 12 inches deep is laid under each rail, and the rails are held to gauge by ties or tie rods placed at frequent intervals. Sometimes the concrete is made a continuous bed under the entire track. In most large cities the concrete foundation is used under all paving; and consequently, when concrete is used instead of ties to support the rails, this concrete is simply a continuation of the paving foundation. Where ties are used, they are laid sometimes in gravel, crushed stone, or sand, although frequently, in the largest cities, they are embedded in concrete. Sometimes this concrete is extended under the ties, and sometimes it is simply put around the ties.



Street Ry. Journal

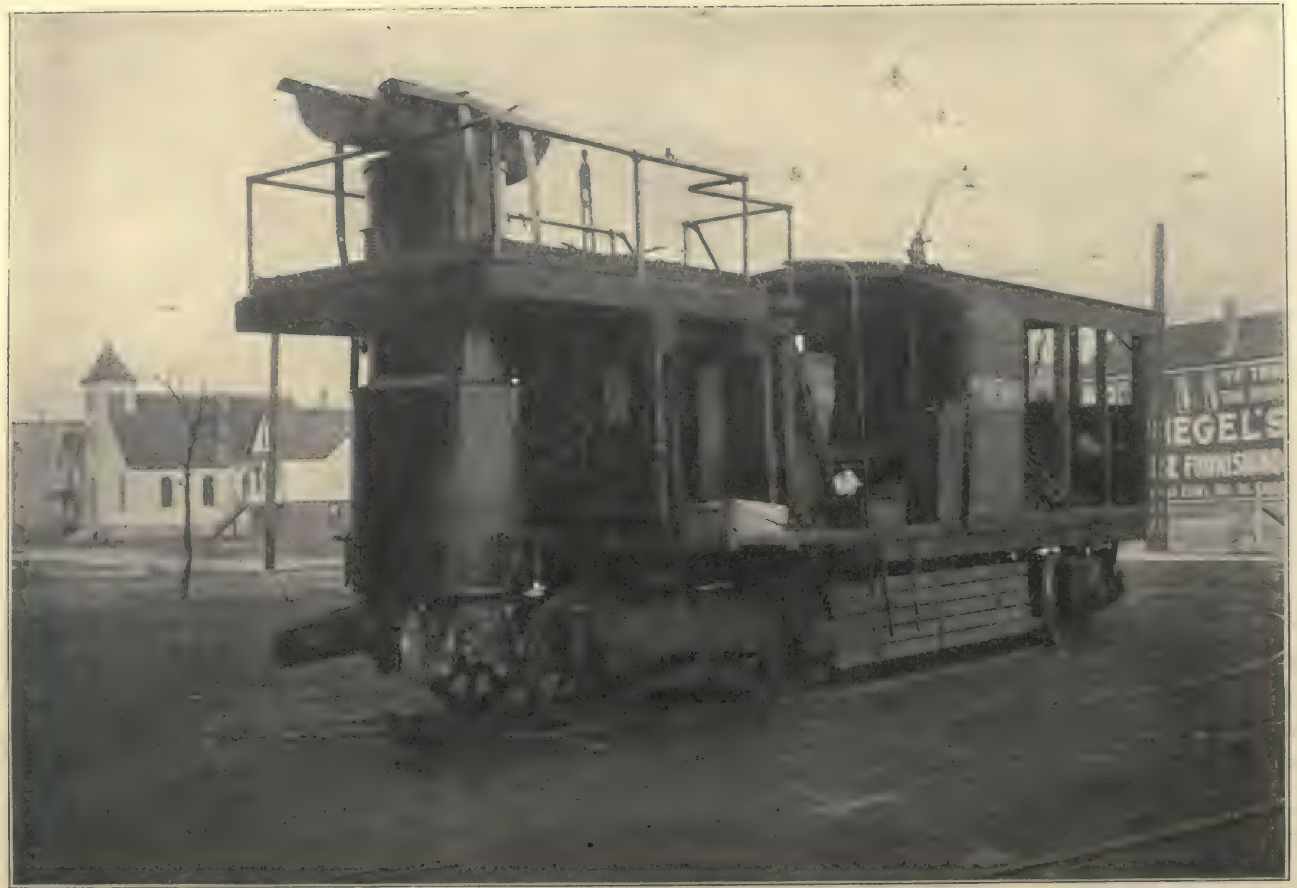
Fig. 78. Standard A. S. C. E. Rail and One Joint Plate.

Ballast. A ballast of gravel, broken stone, cinders, or other material which is self draining and which will pack to form a solid bed under the ties, should be used to get the best results under all forms of tie construction, whether in paved streets or on a private right of way, as on an interurban road. Of course, if concrete is placed under the ties, the gravel or rock ballast is not necessary. If ties are placed directly in soft earth, which forms mud when wet, they will work up and down under the weight of passing trains, and an insecure foundation for the track will be the result.

Joints. The matter of securing a proper joint for fastening together the ends of rails so as to make a smooth riding track without appreciable jar or jolt when the wheels pass a joint, has been given much study by electric railway engineers. A section through an ordinary bolted angle-bar joint is shown in Fig. 75. This joint is formed by bolting a couple of bars, one on each side of the rails. The edges of these bars are made accurately to such an angle that they will wedge in between the head and base of the rail as the bolts are tightened; hence the name *angle bars.* This is the form of joint generally used on steam railroads and on electric roads in exposed track, or in track where the joints are easily accessible, as in dirt streets. In paved streets, the undesirability of tearing up the pavement frequently to tighten the bolts on such joints, has led to the invention of several other types, which will be described later. Nevertheless very good results have been obtained in recent years with bolted joints laid in paved streets where care has been given to details in laying the track, and where the joints have been tightened several times before the paving is finally laid around them.

Welded Joints. Several forms of welded joints are in use. All these welded joints fasten the ends of the rails together so that the rail is practically continuous—just as if there were no joints—so far as the running surface of the rail is concerned. It was thought at one time that a continuous rail would be an impossibility because of the contraction and expansion of the rail under heat and cold, which, it was thought, would tend to pull the rails apart in cold weather and to cause them to bend and buckle out of line in hot weather. Experience has conclusively shown, however, that contraction and expansion are not to be feared when the track is laid in a street where it is covered with paving material or dirt. The paving tends to hold the track in line, and to protect it from extremes of heat and cold. The reason that contraction and expansion do not work havoc on track with welded joints, is probably that the rails have enough elasticity to provide for the contraction and expansion without breaking.

It is found that the best results are secured by welding rail joints during cool weather, so that the effect of contraction in the coldest weather will be minimum. In this case, of course, there will be considerable expansion of the track in the hottest weather,



PORTABLE CUPOLA FOR CAST-WELDING JOINTS OF STREET CAR RAILS.

but this does not cause serious bending of the rails; whereas occasionally, if the track is welded in very hot weather, the contraction in winter will cause the joint to break.

Cast-Welded Joints. The process of cast-welding joints consists in pouring very hot cast iron into a mould placed around the ends of the rails. These moulds are of iron; and to prevent their sticking to the joint when it is cast, they are painted inside with a mixture of linseed oil and graphite. Iron is usually poured so hot that, before it cools, the base of the rail in the center of the molten joint becomes partially melted, thus causing a true union of the steel rail and cast-iron joint. This makes the joint solid mechanically and a good electrical conductor. To supply melted cast iron during the process of cast-welding joints on the street, a small portable cupola on wheels is employed. Fig. 79 gives an idea of the process of making cast-welded joints.

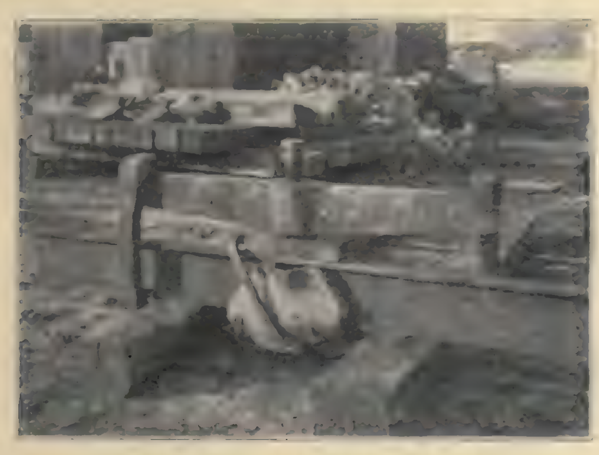


Fig. 79. Process of Cast-Welding Joint.

Electrically Welded Joints. An electrically welded joint is made by welding steel blocks to the rail ends. A steel block is placed on each side of the joint, and current of very large volume is passed through from one block to the other. This current is so large that the electrical resistance between the rail and steel block causes that point to become molten. Current is then shut off, and the joint allowed to cool. There is in this case a true weld between the steel blocks and the rails and joint.

An electric welding outfit being expensive to maintain and operate, this process is used only where a large amount of welding can be done at once. Current is taken from the trolley wire. A rotary converter set takes 500-volt direct current from the trolley wire, and converts it into alternating current. This alternating current is taken to a static transformer which reduces the voltage and gives a current of great quantity at low voltage, the latter current being passed through the blocks and rails in the welding process. A massive pair of clamps is used to hold the blocks against the rails, and to conduct the current to and from the joint while it is being welded. These clamps are water-cooled by having water circulated through them so that they will not become overheated at the point of contact with the steel blocks.

Thermit Welding. A process of welding rail joints which was developed after the cast-welding and electric-welding processes, is known as the *Goldschmidt process,* which makes use of a material called "thermit" for supplying heat to make the weld. A mould is placed around the joint and the thermit is put in this mould and ignited. The heat produced by the thermit is so intense as to reduce the iron in the thermit mixture and make a welded joint. The thermit consists of a mixture of finely powdered aluminum and iron oxide. When this is ignited, the aluminum oxidizes, that is, absorbs oxygen so rapidly that an intense heat is the result. In the process of oxidation, the aluminum takes the oxygen from the oxide of iron, leaving molten metallic iron, which metallic iron makes the weld by union with the molten rail ends. This process has the advantage over other welding processes, of not requiring an elaborate apparatus and a large crew of men to operate it; and consequently it can be used where but a few joints are to be welded.

Bonding and Return Circuits. When the track rails are used as the conductors, as is usually the case, it is necessary to see that the electrical conductivity of the rail joints does not offer too high a resistance to the passage of the current. For this reason, when bolted or angle-bar joints are used, the rails are bonded together by means of copper bonds. It was soon found after electric roads were in use a short time, that unless the rail ends were so bonded, the resistance of the joints was so great as to cause great loss of power in the track. First, small iron bonds were used; but these bonds were so insufficient that large copper-wire bonds soon began to be used; and at the present time, on large roads, bonds of heavy copper cable are common. The resistance of a steel rail, such as used in city streets, is about eleven times that of copper. In order to secure as great carrying capacity at the rail joint as is afforded by the unbroken rail, it is therefore necessary to install bonds having a total cross-section $\frac{1}{11}$ that of the rail. Where welded joints are used, bonding is unnecessary, except at crossings and switches where bolted joints are employed. Where track is welded, however, cross bonds should be put in at frequent intervals from one rail to another, and, if the track is double, from one track to the other, so that if one of the track rails breaks at a joint there will be a path around the break for the current.

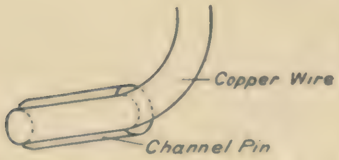


Fig. 80. Channel Pin Bond.

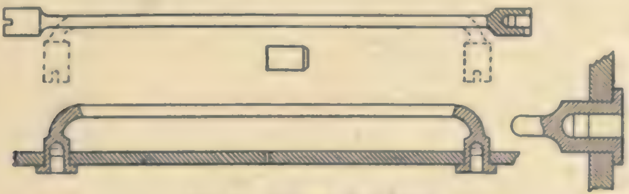


Fig. 81. Chicago Rail Bond.

A great many schemes have been devised to insure good contact between the copper bond and the rail, as the terminal is the weak point in any bond. One of the earliest and most efficient of small bonds was made by the use of channel pins, Fig. 80. This bond consisted of a piece of copper wire having its ends placed in the holes in the rail ends. Alongside this wire, a channel pin was driven in. The objection to the channel pin was the small area of contact between the copper bond and rail.

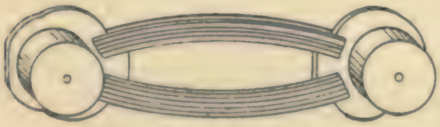


Fig. 82. Rail Bond.

Next after the channel pin came the Chicago type of bond, Fig. 81, which is a piece of heavy copper wire with thimbles forged on the ends. These thimbles were placed in accurately fitted holes in the rail ends, and a wedge-shaped steel pin was driven into the thimbles to expand them tightly into the hole in the rail. Several other bonds using modifications of this principle are in use.

A type of bond in very common use consists of solid copper rivet-shaped terminals, Fig. 82. Between these terminals is a piece of flexible stranded copper cable, made flat to go under the angle bars. In one type the terminal lugs are cast around the ends of the cables, and in another type the cables are forged at their ends into solid rivet-like terminals. These terminal rivets were first applied as any other rivets, with the use of a riveting hammer. Because of the difficulty of thoroughly expanding such large rivets into the holes made for them in the rails, it has become customary to compress these rivets either with a screw press or a portable hydraulic press, which brings such great pressure to bear on the opposite ends of the rivet that it is forced to expand itself so as to fill the hole in the rail completely. This expansion is made possible by the ductile character of the copper. This great ductility characteristic of copper, however, has been the source of one of the difficulties in connection with rail bonding, because the soft copper terminal has a tendency to work loose in the hole made for it in the rail. It is practically impossible to maintain good bonding where the rail joints are so loose as to allow considerable motion between the rail ends.

Several types of bonds have been introduced, in which the contact between the rail and bond is made by an extra piece or thimble.

Another method of expanding bond terminals into the holes made to receive them, is that employed in the General Electric Company's bond. In it a soft pin in the center of the terminal is expanded by compression of the terminal so that it forces the copper surrounding it outward. The copper terminal, in expanding to fill the hole, is therefore backed by the steel center pin.

All types of bonds must be installed with great care if they are to be efficient. Unless the bond terminal thoroughly fills the hole and is tightly expanded into it, moisture will creep into the space between the copper and the iron, and the copper will become coated with a non-conducting scale which destroys the conductivity of the contact.

The *plastic* rail bond, so called because it depends for the contact between the rail and the bond upon a plastic, putty-like alloy of mercury and some other metal, is applied in a number of different ways. One form consists of a strip of copper held by a spring against the rail ends under the fish-plate. The rail ends at the point of contact with this strip of copper are amalgamated and made bright by the use of a mercury compound similar to the plastic alloy. These points of contact are then daubed with plastic alloy, and the copper bond plate applied. It is not necessary, with any form of plastic bond, that the mechanical contact be unyielding, as the amalgamated surfaces with the aid of the plastic alloy between them, maintain a good conductivity in spite of any slight motion. The plastic alloy can be applied in a number of other ways, one of which is to drill a hole forming a small cup in the rail base in adjacent rail ends, fill these cups with plastic alloy, and bridge the space between them with a short copper bond having its ends projecting down into the cups.

Resistance of the Track. The resistance of the return circuit is usually much higher than it should be owing to the bad contact of the bonds. The resistance of rails varies greatly with the proportions of carbon, manganese and phosphorus. The following, figures, however, may be regarded as the average.

Weight per Yard.	Resistance Single Rail per Mile.
50	.0253 ohms
60	.0211 "
70	.0180 "
80	.0159 "
90	.014 "

A track laid with continuous rails as in the case of welded joints, would have one-half the resistance given since there are two rails to be considered.

Tests of new unbonded track constructed with rails 60 feet long show that the joints cause an increase of .25 ohms or more per mile.

Several roads in testing bonds consider a bond good when the bond and one foot of the rail over it have a resistance equal to five feet of the solid rail.

Supplementary Return Feeders. On some large roads it is necessary to run additional return feeders from the power house to various points on the system, to supplement the conductivity of the rails. Otherwise the track rails near the power house would have to carry all the current, and in some cases there are not enough such lines of track passing the power house to do this properly. Sometimes these feeders are laid underground in troughs; sometimes they are laid bare in the ground, and sometimes on overhead pole lines. When laid in the ground, frequently old rails are used instead of copper or aluminum cables. The old rails are, of course, thoroughly bonded together with bonds giving a conductivity nearly equal to that of the unbroken rail.

FEEDER SYSTEMS.

There are two general schemes of direct current feeding in common use. One of these is shown in Fig. 83. Here the trolley wire is continuous and is fed into at different points. The long feeders supplying the more distant portion of the road are larger than those supplying the trolley near by, so as to maintain as nearly as is feasible the same potential the entire length of the line. With such a system of feeding, in order to maintain absolutely the same voltage at all points, it would be necessary to have just one trolley feeder and that feeding into the extreme end of the line farthest from the power station and further to make the resistance per 1,000 ft. of trolley and feeder the same as the resistance per 1,000 ft. of the track return circuit. The plan shown in Fig. 83 evidently does not fully carry out these rather impracticable requirements but is in the nature of a compromise, giving a higher potential near the power station than at distant points but nevertheless much more even potential

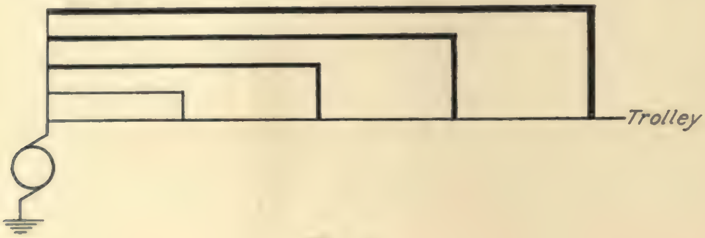


Fig. 83.

than if the heaviest feeders were feeding into the trolley near the power house.

The other plan, shown in Fig. 84, divides the trolley wire into sections and feeds each section through a separate feeder which is calculated of such size as to maintain the same voltage on all the sections with the ordinary load.

In calculating a feeder system a certain probable load is assumed at certain points along the line. This load will manifestly depend on the size and number of cars in operation, grades and many local conditions.

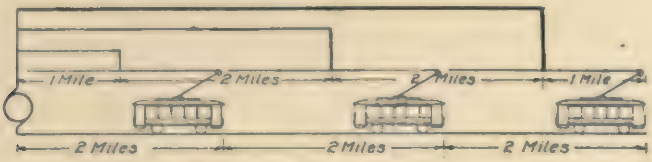


Fig. 84.

Drop in rail section....	3.1 Volts	2.1 Volts	1.05 Volts
Total drop in rail........	3.1 "	5.2 "	6.25 "
Drop in trolley........	20.5 "	20.5 "	20.5 "
Drop in feeder.........	36.4 "	34.3 "	33.25 "
Resistance feeder	.728 Ohms	.686 Ohms	.665 Ohms
Feet per ohm	7253	23000	39700
Size of wire..	No. 1	250,000 C. M.	420,000 C. M.

The following example will show the method pursued. The figures resulting from the calculations are placed immediately below the sections to which they refer in Fig. 84. The rails are assumed to be 70 pound to the yard. These have a resistance of about .018 ohms per mile. Adding one-sixth for additional resistance of bonds gives .021 and since the track is composed of two rails the resistance of the track will be one half of this or .0105 ohms per mile.

The maximum drop in any section occurs when the car is farthest from the power house. Each car is assumed to take 50 amperes and the feeders are to be so designed as to allow a 10 per cent or 60 volts drop.

The current in the two miles of track nearest the power house is 150 amperes, in the next section 100 amperes, and in the last section 50 amperes. The drop in each section is as shown. The drop in the trolley which is 00 wire is, in each section, 20.5 volts. Subtracting from 60 volts the drop in the return circuit and trolley, gives the allowable drop in the feeder.

The resistance of each feeder can be calculated, since the current in each one is 50 amperes. The first feeder is one mile long, the second 3 miles and the third 5 miles, and with these figures the feet per ohm can be computed. The size of wire may be obtained by reference to a table of copper wire resistances.

BLOCK SIGNALS FOR ELECTRIC RAILWAYS.

The simplest block signal used by electric roads is a hand-operated one constructed on the principle shown in the diagram Fig. 85. A double throw switch is placed at each terminal of the section of track that is to be protected.

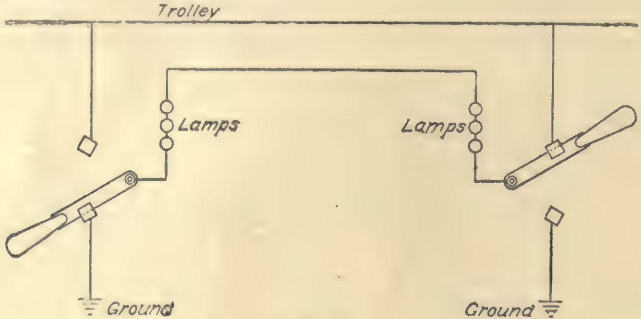


Fig. 85.

The switches have no central position, the knife blade always making contact with one or the other of the terminals shown. If the lamps are lighted, throwing either one of the switches will put them out. If they are not burning, they will be lighted by throwing either one of the switches.

A motorman on reaching a section of track finding the lamps not burning throws the switch. Lamps now burn in each switch box and show that the section is in use. On arriving at the other terminal of the block the switch is thrown, extinguishing the lights and showing that the block is clear.

Automatic signal systems have been devised on the same principle, in which magnets, operated by contacts made by the passage of the trolley wheel, cause the lamps to be lighted and extinguished automatically.

ELECTROLYSIS.

Much has been said about the possibilities of electrolysis of underground metal by the action of the return current of electric railways, when such railways are operated with grounded circuits, as they usually are. If electric current is passed through a liquid from one metal electrode to another, electrolysis will take place; that is, metal will be deposited on the negative pole, and the positive pole or electrode will be dissolved by becoming oxidized from the action of the oxygen collecting at that pole.

In an electric-railway return circuit, there is necessarily a difference of potential between the rails at outlying parts of the system and the rails and other buried pieces of metal located near the power house. Just what this total difference of potential is, depends on the loss of voltage in the return circuit. Thus, suppose there is 25 volts drop in the return circuit between a certain point on the system and the power station. There is, therefore, a pressure of 25 volts tending to force the current through the moist earth from the rails at distant portions of the line, to the rails, water pipes, and other connected metallic structures located in the earth near the power station. The amount of current that will thus flow to earth in preference to remaining in the rails, depends on the relative resistance of the rails, the earth, and the other paths offered to the current to return to the power house.

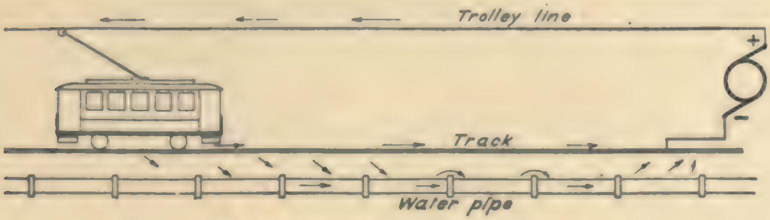


Fig. 86. Showing Electrolytic Action.

To take a very simple case, let us suppose a single-track road, Fig. 86, with a power house at one end, and a parallel line of water pipe on the same street passing the power house. If the positive terminals of the generators are connected to the trolley wire, the current passes, as indicated by the arrows, out over the trolley wire through the cars and to the rails. When it has reached the rails it has the choice of two paths back to the power house. One is through the rails and bonding; the other is through the moist earth to the line of water pipe and back to the power house, leaving the pipe for the rails, at the power house. Should the bonding of the rails be very defective, considerable current might pass through the earth to the water pipe.

Remembering now the principles of electrolysis, we see that the oxidizing action of this flow of current from the rails to the water pipes at the distant portion of the road will tend to destroy the rails, but will not harm the water pipe at that point, as it will tend to deposit metal upon it. When, however, the current arrives at the power house, it must in some way leave this water pipe to get back to the rails, and so to the negative terminals of the generators.

Here we see that there is a chance for electrolysis of the water pipe, because at this point the water pipe forms the positive electrode, which is the one likely to be oxidized and destroyed. This very simple case is taken merely for illustration. In actual practice the conditions are never so simple as this, for there are various pipes located in the ground running in various directions, which complicate the case very much; but we can see from this simple example that the principal place electrolysis of water pipe is to be feared is at points where a large volume of current is leaving the water pipe to take to some other conductor.

As an indication of how much current is likely to be leaving the water pipes at various points, it is customary to measure the voltage between the water pipes and the electric railway track and rails. When this voltage is high, it does not necessarily mean that a large volume of current is leaving the water pipes at the point where these pipes are several volts positive with reference to the rails; but such voltage readings indicate that, if there is a path of sufficiently low resistance through the earth, and if the moisture in the earth is sufficiently impregnated with salts or acids, there will be trouble from an electrolytic action due to a large flow of current. There is obviously no method of measuring exactly the amount of current leaving a water pipe at any given point, since the pipe is buried in the earth. Voltmeter readings between pipes and rails simply serve to give an indication as to where there is likely to be trouble from electrolysis. The danger to underground pipes and other metallic structures from electrolysis has been much overestimated by some people, as the trouble can be overcome by proper care and attention to the return circuit. Trouble from electrolysis, however, is sure to occur unless such care is given.

Prevention of Electrolysis. Remedies for electrolysis may be classified under two heads—general and specific. The general remedy is obviously to make the resistance of the circuit through the rails and supplementary return feeders so low that there will be but little tendency for the current to seek other conductors, such as water and gas pipes and the lead covering of underground cables. This remedy consists in heavy bonding, in ample connections, around switches and special work where the bonding is especially liable to injury, and in additional return conductors at points near the power house to supplement the conductivity of the rails.

It is important that all rail bonds be tested at intervals of six months to one year in order that defective bonds may be located and renewed, as a few defective bonds can greatly lower the efficiency of an otherwise low-resistance circuit.

The specific remedy for electrolysis which may be applied to reduce electrolytic action at certain specific points, consists in connecting the water pipe at the point where electrolysis is taking place, with the rail or other conductor to which the current is flowing. Thus, for example, if it is found that a large amount of current is leaving a water pipe and flowing to the rails or to the negative return feeders at the power house, the electrolytic action at this point can obviously be stopped by connecting the water pipe with the rails by means of a low-resistance copper wire or cable, thereby short-circuiting the points between which electrolytic action is taking place. There are certain cases in which it is advisable to adopt such a specific remedy. It should be remembered, however, that a low-resistance connection of this kind, while it reduces electrolysis at points near the power house, is an added inducement to the current to take to the water pipes at points distant from the power house, because of the decrease in resistance of the water-pipe path to the power house resulting from the introduction of the connection between the water pipe and the negative return feeder at the power house. With the water pipes connected to the return feeders in the vicinity of the power house, the current which flows from the rails to the water pipes at points distant from the power house will obviously cause electrolysis of the rails but not of the water pipes, since the current is passing from the earth to the pipe, and the pipe is negative to the earth. In this case the principal danger is that the high resistance of the joints between the lengths of water pipe will cause current to flow through the earth around each joint, as indicated on some of the joints, Fig. 86, and will cause electrolytic action at each joint. It is evident, however, that the conditions of the track circuit and bonding must be very bad if current would flow over a line of water pipe, with its high-resistance joints, in sufficient volume to cause electrolysis, in preference to the rail-return circuit, especially since ordinarily the resistance offered to the flow of current over the water pipes back to the power house must include the resistance of the earth between the tracks and water pipes.

It is usually considered inadvisable to connect tracks and water pipes at points distant from the power house, because of the danger of electrolysis at water-pipe joints, as just explained.

Methods of testing rail bonds in the track will be explained under the head of "Tests."

POWER SUPPLY AND DISTRIBUTION.

Direct-Current Feeding. As already explained, the majority of electric railways are operated on a 500-volt constant-potential direct-current system with a ground return. A constant potential of 450 to 550 volts is maintained between the trolley wire and track. Where the trolley wire is not sufficient, additional feeders are run from the power house and connected to the trolley wire, the number of feeders depending on the distance from the power house and the traffic.

Booster Feeding. Boosters are sometimes used on long feeder lines where there is a heavy load only a small portion of the time. These boosters are direct-current dynamos that are connected in series with the feeder upon which the voltage is to be raised above the regular power-house voltage. The booster may be driven either by a small steam engine or by an electric motor. The simplest form of booster is a series-wound dynamo. A booster armature must, of course, be of sufficient current capacity to pass all the current that will be required on its feeder. The voltage yielded by this dynamo, plus the power-station voltage, is the voltage of the boosted feeder as it leaves the power house. Supposing that a series-wound booster will give 125 volts at full load; it is obvious that being series-wound it will give no voltage at no load. The voltage will increase approximately as the load on the feeder increases; and since the drop in voltage on the feeder for which the booster is to compensate also varies with the load, the action of the booster is simply to add sufficient voltage to its feeder at any instant to compensate for the line loss upon that feeder and to maintain approximately constant potential at the far end of the feeder. Boosters raising the power-station voltage of a feeder more than 250 volts above the normal power-station voltage, are not common, though cases are on record where a feeder has been boosted as high as 1,100 volts above the power-station voltage. Since all the power used in driving a booster is wasted in line loss, this method of feeding is not economical; but where used only a few days out of the year it is sometimes to be preferred to a heavy investment in feeders. The investment in feeders might involve more interest charges than the cost of power wasted in booster feeding would amount to.

Alternating-Current Transmission. High-tension alternating-current transmission *to* substations, with direct-current distribution *from* substations, is extensively used on long interurban roads, and on large city street-railway systems where power is to be distributed over a wide area. In such cases the power house is equipped with alternating-current dynamos supplying high-tension three-phase alternating current to high-tension transmission lines or feeders. These high-tension feeders are taken to substations located at various points on the road, where the voltage is reduced by step-down transformers; and these transformers supply current to operate rotary converters, which convert from alternating to direct current for use on the trolley.

The advantage of this system of high-tension distribution is that, owing to the high transmission voltage, there is but a small loss in the high-tension lines, which lines can be made very small, and will thus involve but little copper investment. The substations can be located at frequent intervals, so that the distance the 500-volt direct-current must be conducted to supply the cars is not great. Current from one power house can thus be distributed over a very large system in cases where, if the 500-volt direct-current system of distribution were used, the cost of feeders for distributing such a low-voltage current would be prohibitive. Were the alternating-current high-tension scheme of distribution not used, it would be necessary to have a number of small power houses at various points on the system instead of one large power house. The cost of operation of several small power plants per kilowatt output, is likely to be much greater than that of one large power plant. The first cost of the alternating-current distributing system, including power house

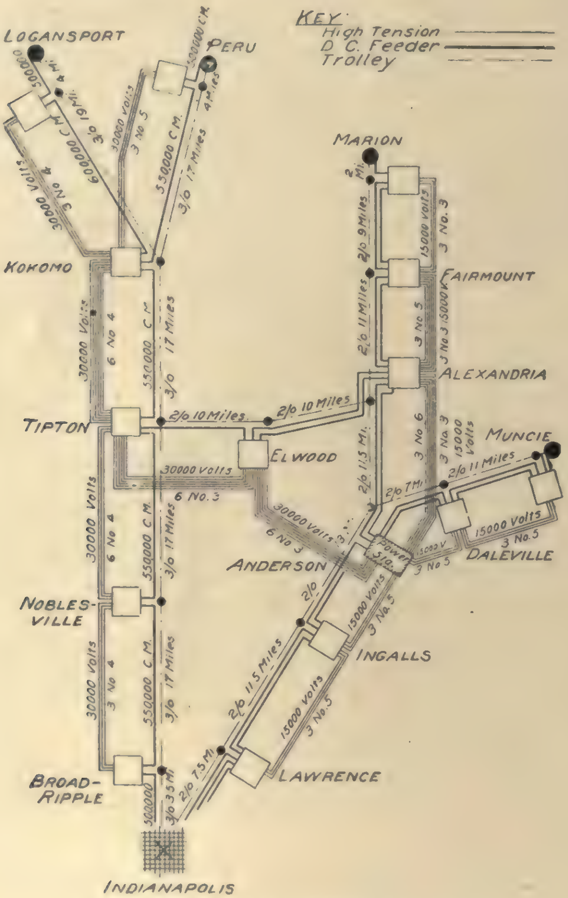
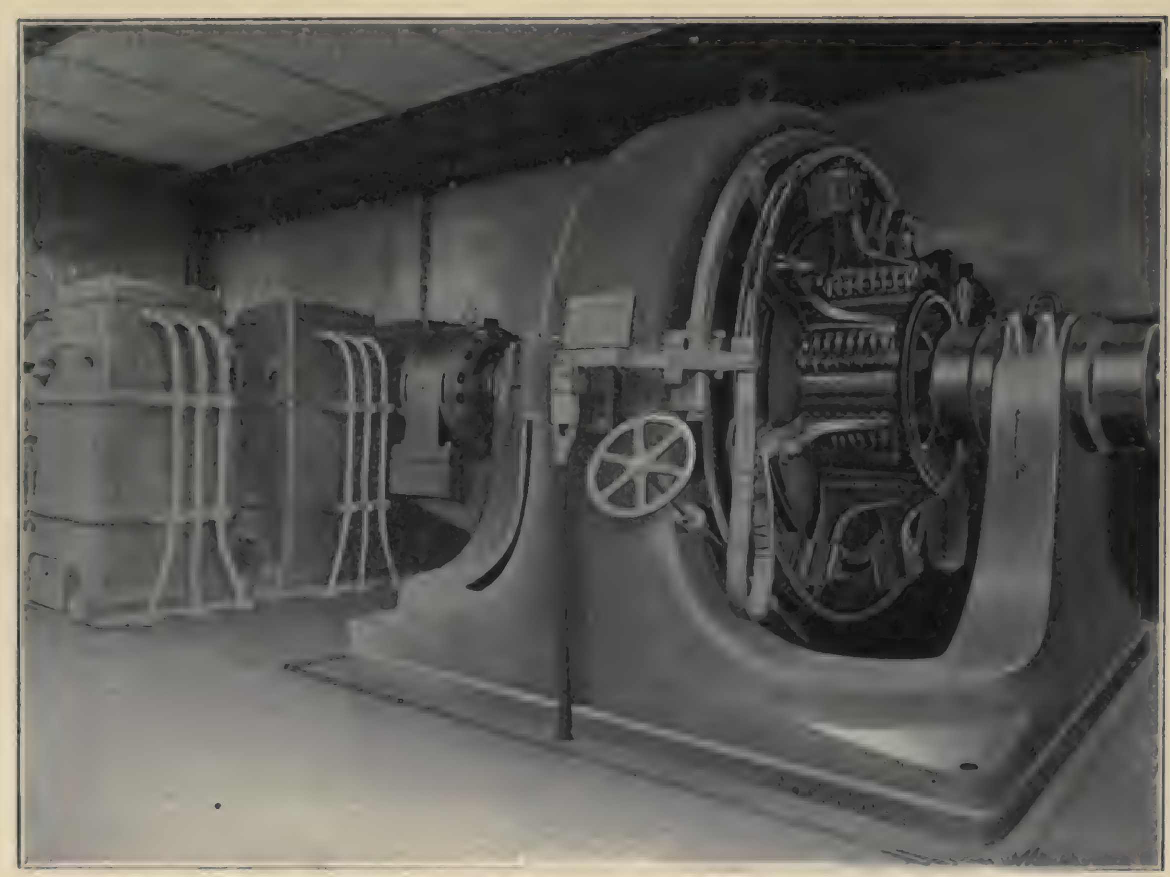


Fig. 87. Diagram of Distributing System.



800 K.W. THREE-PHASE ROTARY CONVERTER AND AIR BLAST TRANSFORMERS.

Manhattan Railway Company, New York City.

and substations, is likely to be considerably higher than would be the cost of a number of small power houses; but in cases where alternating-current distribution has been installed, it has been figured that the cost of operation of the central power house with alternating-current distribution would be sufficiently low as compared with several small ones to pay more than the interest on this extra investment.

A System of Distribution for an Interurban Railway. The typical features of a high tension system of distribution for an extensive interurban railway system are shown in Fig. 87, which represents the electrical transmission and distribution system of the Indiana Union Traction Company. The central power station at Anderson feeds into thirteen rotary converter substations from 7 to 65 miles distant from the power house. The substations east of Indianapolis are fed at 16,000 volts and are placed about 11 miles apart. The substations due north of Indianapolis are located at intervals of about 17 miles and are fed at 30,000 volts.

The power station at Anderson has a total capacity of 5,000 K. W. The substations vary in capacity from 250 to 1,500 K. W.

Efficiency of Transmission Systems. The average efficiency of a high tension transmission system for a certain interurban electric railway system are given below. Current was generated at 380 volts. The step-up transformers raised it to a potential of 16,000 volts at which pressure it was transmitted to eight substations at distances from 10 to 40 miles from the power station. It was then stepped down to 380 volts and converted to direct current by a rotary converter. The tests extended over a period of three days. The efficiency of the step-up transformers was 95 per cent; of the high tension line 92.9 per cent; of the step-down transformers 95 per cent; and of the rotary converters 88 per cent; giving a total efficiency of the transmission system of 73.5 per cent.

Power House Location. A power house is usually located where coal and water supply can be cheaply obtained. For this reason it is placed either on some line of railroad or where coal can be taken to it over the electric railway.

As it is always desirable to operate the engines in connection with condensers, on account of the saving in fuel, which is approximately 20 per cent with condensers, power stations are located, when possible, near rivers and ponds from which a large supply of cold water for condensation of exhaust steam can be obtained. Where no such natural water supply is available, it has become customary to provide means for artificially cooling a sufficiently large supply of water for condensation. One method is to erect a number of towers, so constructed that the water when pumped to the top will fall through a structure that breaks the water up into fine spray as it falls, thus allowing it to cool by evaporation so that it can be used again for the condensers when it arrives at the bottom of the tower. Where more room is available, ponds are sometimes excavated near the power house, and the water is made to flow back and forth through a series of troughs located above the pond, and it is thus cooled.

Where a power station is of the direct-current type, operating at 500 to 600 volts, it is desirable to have it as near the center of electrical distribution as possible, in order to keep down the amount of investment in the feed wire; but it is more important to have it located near a cheap coal and water supply than exactly at the center of distribution.

It is also desirable to have the station located where there is room for coal storage, on account of the chances for interruption of the coal supply by strikes, railroad blockades, and other causes beyond the company's control. The continuity of the coal supply is also another argument against placing the station where dependence must be placed upon wagons or inadequate railroad facilities.

Coal handling, after the coal has reached the station, is done by hand in the smaller power stations; but in larger power stations it has come to be the general practice to do as much of the handling as possible by means of automatic coal conveyors. The most elaborate power stations have means for dumping coal from cars into hoppers, from which it is conveyed by an endless chain provided with buckets, called a *coal conveyor,* to storage bins. Coal conveyors also take the coal from the storage bins, and deposit it in the hoppers of mechanical stokers in front of the boilers. Ashes are conveyed from under the boilers by the same kind of conveyors, and are dumped into hoppers, whence they are drawn into cars or wagons to be hauled away.

The coal, having been deposited in hoppers at the boiler front, is automatically fed into the furnaces by automatic stokers. One type of automatic stoker in common use is of the chain-grate or link-belt type, which is constructed like an endless sprocket chain, with links composed of heavy cast-iron blocks that serve as grate bars. This link belt or chain is kept in constant, slow motion by a small stoker engine or motor which operates all the stokers of a line of boilers. The coal is fed from the hopper on to the chain grate, and the chain is slowly moved under the boilers. As the coal on that part of the grate under the boilers is on fire, the fresh coal as it enters the furnaces is soon ignited. The grate is run at such a rate, and the thickness of the coal is so adjusted, that the coal is burned to an ash by the time it has traveled to the back of the furnace. There the grate turns down over a sprocket wheel, and the ashes are dumped into the ash pit as the grate revolves.

The boilers in most common use in large American electric-railway power houses are of the water-tube type, in which water is contained inside of a bank of tubes, the ends of these tubes being connected to drums or headers. The horizontal return-tubular type of boiler is used in many of the smaller power stations, and vertical boilers are also in use.

The engines in the larger and more economical stations are generally of the Corliss compound-condensing type, running at speeds of from 60 to 120 revolutions per minute, according to the size of the unit. The smaller the unit, the higher the speed. In the smaller and older stations, simple Corliss engines belted to generators are frequently found, and high-speed engines also are used. It is the almost universal custom now, to place the generator directly on the engine shaft, making a direct-connected unit.

Steam turbines, in which the steam acts in jets against the blades of a turbine wheel, are beginning to come into use at the present time. These turbines rotate at very high speed, the largest and slowest speed-units running 600 r.p.m., and others at higher rates. As the output of any generator varies directly according to its speed, a very much smaller generator can be used when coupled to a high-speed steam turbine, to obtain a given output, than if the generator must be coupled to a Corliss steam engine which revolves at very low speed. The economy of the steam turbine at full load is about that of a compound-condensing Corliss engine, but is better on light loads than the engine. The turbine requires less building space and a much less expensive foundation.

Railway generators or dynamos for direct current are usually built with compound-wound fields, so that, as the load increases, they will automatically raise the voltage at their terminals to compensate for the drop in the feeders and to maintain a constant potential at the cars. Thus, if the line loss on a system is 10 per cent, or 50 volts at full load, the generators will be provided with shunt fields of sufficient strength to give 500 volts at no load, and with series field coils which will add to the field strength enough to give 550 volts at full load. The amount of "compounding"—which is the

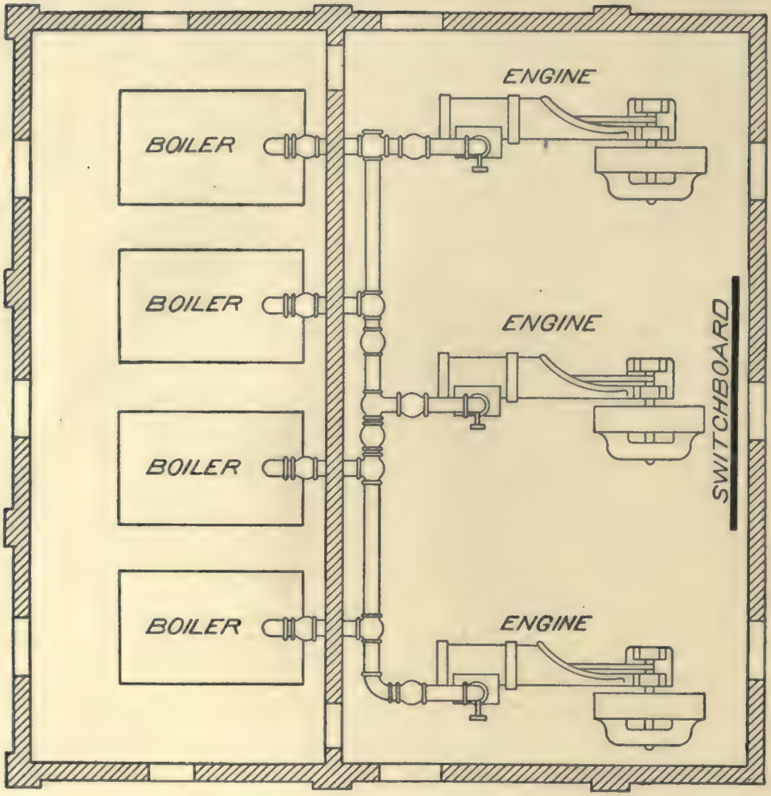


Fig. 88. Plan of Power House.

term applied to this method of increasing voltage—may be any amount within reasonable limits. The pressure maintained at different companies' electric-railway power houses varies, but is usually between 500 and 600 volts.

Alternating-Current Generators. Alternating-current generators used for generating alternating current to be distributed at high tension, are generally constructed to give a three-phase current at 25 cycles per second. The voltage of these alternating-current generators is sometimes the voltage at which the power is to be transmitted, if the distances are not too great. A number of stations have alternating-current generators giving 6,600 volts at their terminals, which is a voltage well adapted to high-tension distribution within the limits of a large city. However, generators giving 11,000 volts at their terminals are now becoming common. For higher voltages than this, it is considered necessary to use step-up transformers, in order to raise the voltage to the proper pressure for transmission over long distances. In such cases there is no object in having a high generator voltage. At such stations the voltage of the generators adopted may be anything desired, and it varies according to the ideas of the constructing engineer. Voltages of 400, 1,000, and 2,300 are among those in most common use.

Double-Current Generators. Double-current generators are sometimes used, which generators will give direct current at a commutator at one end of the armature for use on a 500-volt direct-current distribution system supplying the trolley direct. The other end of the armature has collector rings from which the three-phase alternating current is obtained, which can be taken to step-up transformers and raised to a sufficient pressure for high-tension transmission to substations at distant parts of the road. The same generator can therefore be used on both the direct-current and the high-tension alternating-current distribution.

General Plan of Power Stations. The general plan of an electric-railway power station is usually such that the building can be extended and more boilers, engines and generators added without disturbing the symmetrical design of the station. Thus, the boilers and engines are placed as in Fig. 88, in parallel rows, although almost invariably in different rooms separated by a fire wall. By adding to the row of engines and to the row of boilers, the station capacity can be increased. Other arrangements are sometimes required by circumstances; but this is the most common arrangement and gives the greatest capacity with the minimum amount of steam piping. Large stations are sometimes constructed with a boiler room of several floors and with boilers on each floor, in order to save ground space and bring the boilers near to the large engine units so that there will not be an excessive amount of steam piping.

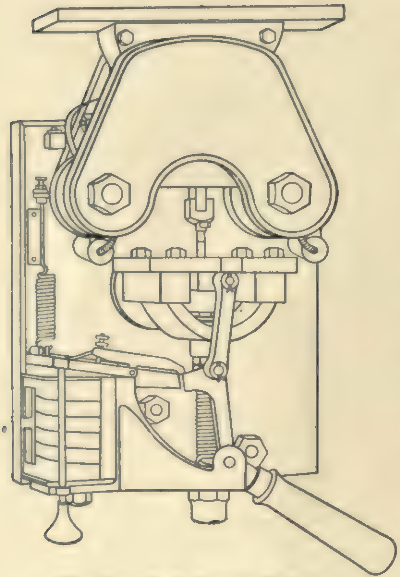


Fig. 89*a*. G. E. Circuit Breaker.

Switchboards. Direct-current stations have switchboards, which may be considered under two general classes — *generator boards* and *feeder boards*. Each board consists of panels.

Generator D. C. Panels. The generator panel usually contains an automatic circuit breaker which will open the main circuit to the generator in case of an overload due to a short circuit. These circuit breakers consist of a coil in the main circuit, which acts upon a solenoid. When the current in the coil exceeds a certain amount, the solenoid is drawn in, and a trigger is tripped which allows the circuit breaker to fly open under the pressure of a spring. In the General Electric circuit breaker, the main contact is made by heavy copper jaws, but the last breaking of the contact is made between points which are under the influence of a magnetic field. This magnetic field blows out the heavy arc that would otherwise be established. On the I-T-E, the Westinghouse and most other types of circuit breaker, the breaking of the contact takes place between carbon points, which are not so readily destroyed by an arc as are copper contacts, and which are more cheaply renewed. The main contact through the circuit breaker, in either type, is made between copper jaws of sufficient cross-section for carrying the current without heating.

These jaws open before the current is finally broken by the smaller contacts which take the final arc.

In Fig. 89*a* is seen a General Electric circuit breaker with the magnetic blow-out coils at the top, the solenoid at the left, and the handle for resetting the circuit breaker at the bottom. The small handle for tripping the circuit breaker, when it is desired to open the circuit by hand, is shown just under the solenoid.

An I-T-E circuit breaker is shown in Fig. 89*b*. This is of the type previously mentioned, in which the break occurs between carbon contacts and there is no magnetic blow-out.

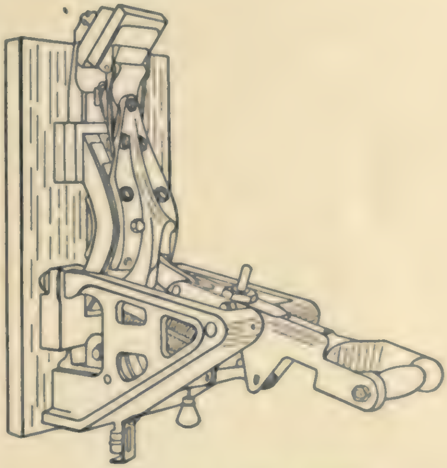


Fig. 89*b*. I-T-E Circuit Breaker.

In addition to the circuit breaker there is usually an ammeter, to indicate the current passing from the generator; and a rheostat handle, geared to a rheostat back of the board, for cutting in and out more or less resistance in the shunt field coils of the generator so as to reduce or raise the voltage. There is a small switch for opening and closing the circuit through the shunt field coils.

The main leads from the generator pass through two single-pole quick-break knife switches. The most recent practice is to have the switches on the switchboard in only the positive and negative leads from the generator, leaving connection to the equalizer to be made by a switch located on or near the generator. However, all three leads may be taken to the switchboard, and a three-pole knife switch may be used instead of the positive and negative switches spoken of.

In Fig. 90 is given a simple diagram of the general relative connection of generators and feeders in a direct-current railway power station. It is seen that the generators are connected in parallel across the positive and negative bus bar. There is a third bus bar —called an "equalizing bus"—which connects in parallel the series coils of all the generator fields. The object of this equalizer is to prevent the weakening of the series field of any one generator, so as to allow it to take current and to act as a motor instead of as a generator.

Starting Up a Generator. Suppose that a new generator is to be started up and connected to the bus bars in addition to others already in operation. The engine of that generator is first brought up to speed. The switch controlling the shunt field circuit is then closed, causing current to flow through the shunt fields; and the generator begins to "build up," its voltage gradually rising until it approximates that upon the bus bars. Before the generator is thrown in parallel with the others by connecting it with the bus bars, it is important that its voltage be nearly the same as that of the bus bars. Otherwise, when connected to the bus bars, it might take more than its share of the load; while, on the other hand, if its voltage were too low, it might act as a motor, taking current from the bus bars. The voltage of the bus bars in a railway station is constantly fluctuating, owing to the varying load and to the fact that generators are often compounded, as before mentioned, in order to compensate for the line loss.

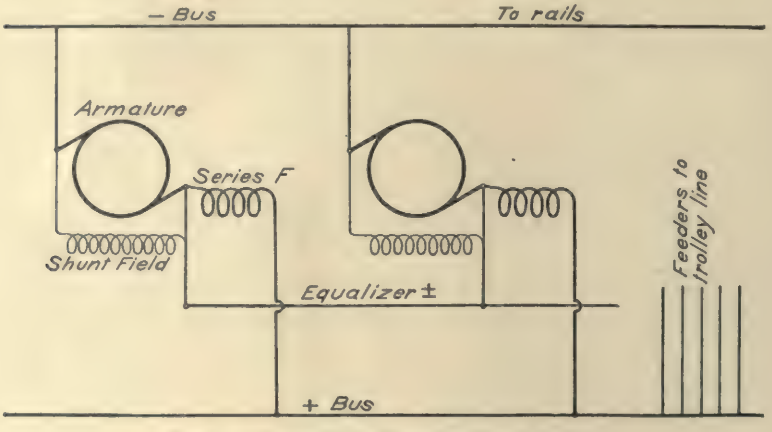


Fig. 90. Connection of Generators and Feeders.

In order that the voltage of the generator to be thrown in shall vary in accordance with the bus bar voltage, the next step in the operation is to close the positive switch, assuming that the equalizer switch on the generator has already been closed. This throws the series field of the new generator in parallel with the series fields of the other generators. The voltage of the new generator will therefore vary just as the voltage on the bus bars; and, by adjusting the resistance of the shunt field, this voltage can be adjusted so as to be the same as that on the bus bars. The voltages on the bus bars and on the new generator are measured usually by a large voltmeter on a bracket at the end of the generator switchboard. By means of a voltmeter plug or of a push button on the generator panel, the volt-

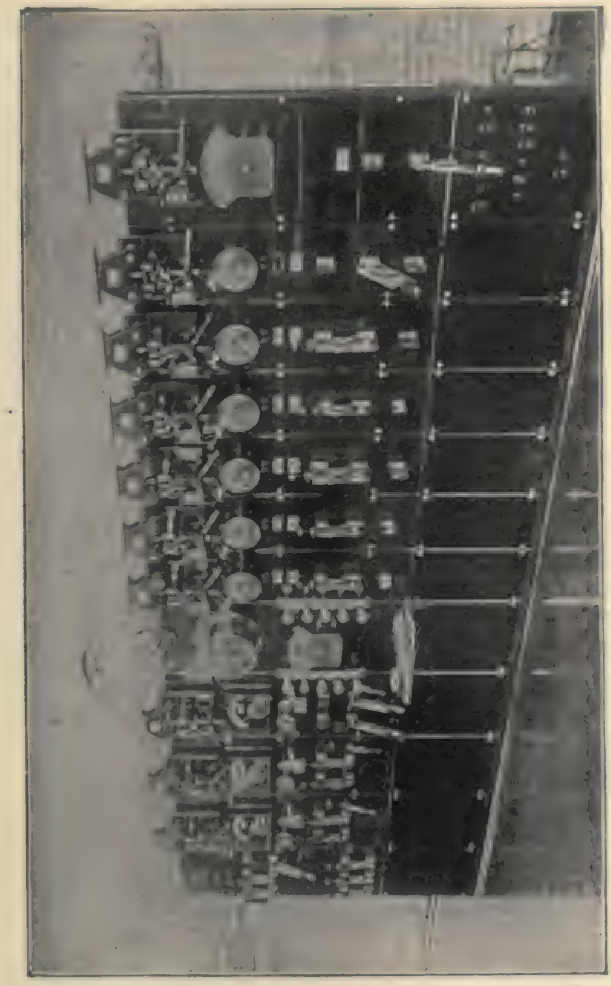


Fig. 91. Railway Switchboard.

meter can be connected either to the bus bars or to the new generator. When the two voltages are the same, the negative switch of the new generator can be closed, and it will operate in parallel with the other generators, taking its share of the load. If the attendant sees that any generator is not taking its share, he can raise its voltage by cutting out some of the resistance in series with its shunt field, and this makes that generator take more load.

Feeder Panel. The feeder panel is simpler than the generator panel, since it usually handles only the positive side of the circuit. Frequently two feeders are run on a single panel side by side. The feeder panel has an automatic circuit breaker, an ammeter for indicating the current on that feeder, and a single-pole switch for connecting the feeder to the bus bar. All generators feed into a common set of bus bars; and the positive bus bar continues back of the feeder panels so that all feeders can draw current from the bus bars. Fig. 91 shows a railway switchboard with 7 feeder panels at the right; 4 generator panels at the left; and, in the middle, a panel with an ammeter and recording wattmeter for measuring total output.

In some stations two and even three sets of bus bars are used, as it may be desired to operate different parts of the system at different voltages or to feed a higher voltage to the longer lines than to those near the station. In such a case double-throw switches are provided for connecting feeders and generators to either set of bus bars.

Alternating-Current Switchboards. In an alternating-current station, generator switchboards are radically different from those in a direct-current station. Practice in alternating-current generator switchboards has not yet been so fully standardized and is not so uniform as in direct-current railway switchboards. There is always, however, a three-pole main switch for opening and closing the main three wires from the three-phase generator. Automatic circuit breakers are usually provided, as well as indicating ammeters and wattmeters to show the output.

Indicating wattmeters, recording the number of watt hours passing through them, are frequently used both on alternating and direct-current generator panels.

A station usually has what is called a "total load" panel, which has a recording wattmeter measuring the total output of the station in kilowatt hours. This panel also has an ammeter indicating the total station load.

High-Tension Oil Switches. Alternating-current generators for high voltages usually have oil switches to interrupt the main circuit, that is, switches in which the contact is made and broken under oil. These switches have been found very efficient in preventing the formation of a destructive arc upon the opening of a high-voltage circuit, on circuits up to 60,000 volts. Some of the larger oil switches are operated by electric motors or solenoids. The machine-type oil switch of the General Electric Company has the motive power for operating the switches, stored up in a spring. The spring is wound up by a small electric motor. This motor operates every time the switch is opened or closed, and winds up the spring enough to compensate for the amount it was unwound in operating the switch. Each circuit is broken under oil in a long tube, and these tubes are mounted in individual cells, each cell being separated from the next by a masonry wall so that there can be no flashing across from one leg of the circuit to another in case of any defect in the switch. All the high-tension wiring to and from such switches, is taken either in lead-covered cables, or on bus bars separated from each other by masonry walls to prevent the spread of short circuits. These precautions are necessary because of the great length of arc that may be established between adjacent high-tension conductors.

Where alternating-current generators of low voltage are used in connection with step-up transformers, one practice is to have the switches for each generator directly in the generator leads, between the generators and the step-up transformers, in the low-voltage circuit.

Another practice which has recently been introduced, is to consider each generator with its step-up transformers as a unit and to connect the generator permanently with its bank of transformers, and to control this unit by a single three-pole machine-operated oil switch. In this case there are no switchboard switches between generators and transformers, and this simplifies the switchboard considerably. There must be switches on the high-tension side of the transformers in any event.

The switchboard for rotary converters in the substations is, of course, a combination of alternating and direct-current apparatus. The direct-current ends of the rotary converters are treated almost exactly like direct-current railway generators; and their switchboard panels are similarly equipped, except that usually there is a rheostat that can be connected in series with the armature whereby a rotary converter can be brought up to speed from a state of rest by connecting it with the direct-current bus bars of the substation.

The alternating-current end of the rotary converter is supplied through switches in the alternating-current leads from the step-down transformers. A rotary converter can be started from a state of rest by connecting it to the alternating-current leads through the medium of compensating coils which reduce the voltage. A very heavy current is required to do this, as the motor thus starts as a very inefficient induction motor with a very low power factor.

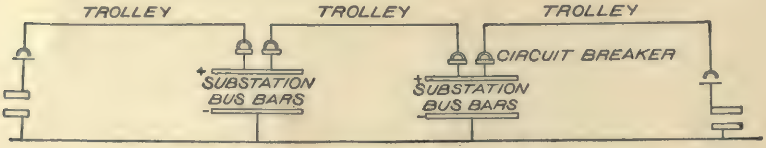


Fig. 92. Connection of Substations.

There are usually but two direct-current feeder panels in a substation of an interurban electric road. One of these feeders is to supply the trolley or third rail extending in one direction from the substation, and the other feeds that extending in the other direction from the substation. The trolley or third rail has a section insulator directly at the substation. When both feeders are connected to the bus bars, it is evident that this section insulator is short-circuited through the medium of the substation bus bars, every substation on the line being connected in this way, as indicated in Fig. 92. It is seen that, should a short circuit occur on any section, it would open the circuit breakers at the substations at both ends, and that section would not interfere with the balance of the road. At the same time, when the road is in normal operation and there is an unusually heavy load between any two substations, the other substations along the line can help out those nearest to the load by feeding through the bus bars of the nearest substation.

The high-tension apparatus at a substation consists usually of a bank of high-tension lightning arresters; high-tension switches, for shutting off the high-tension current; and step-down transformers, for reducing from the high transmission voltage to the 370 volts commonly fed to the alternating-current end of railway rotary converters.

Storage Batteries in Stations. Storage batteries are frequently used both in substations and in direct-current power stations. They may be connected directly across the line and allowed to "float," as it is termed; or they may be used in connection with storage-battery boosters, which will cause the storage battery to take the fluctuations in the load and to give a constant load on the rotary converters or power station. The action of storage-battery boosters which cause the storage battery to be charged automatically at light loads and to discharge and assist the station at heavy loads, is explained in the paper on "Storage Batteries."

ALTERNATING-CURRENT SYSTEMS.

So far this paper has been devoted almost entirely to electric railway systems employing 500-volt direct-current motors on the cars, since this is the system almost universally employed on electric railways at the present time. There are, however, several systems employing alternating-current motors on cars, which have already been used experimentally and to some extent commercially. Some of these give promise of coming into extensive use.

Three-Phase Motors. On several roads in Europe three-phase induction motors are employed. These induction motors are operated by three-phase alternating current taken direct from the trolley wires. As three conductors are necessary, two trolley wires are used, with the rails as the third conductor. The two principal objections to the system are the necessity of two trolley wires, and the fact that the induction motor operates very much like a direct-current shunt motor in that it is a constant-speed motor and not adapted to variable-speed work. The power factor is low in starting; that is, a great volume of current is taken, although, owing to the voltage and the current not being in phase, the actual energy consumed is small.

Single-Phase Motors. The Westinghouse Electric & Manufacturing Company has brought out a railway motor adapted to operate on single-phase alternating-current circuits. This motor is very similar in construction to the ordinary series-wound 500-volt direct-current railway motor. It has, however, more field poles than the ordinary direct-current motor; and the pole pieces are laminated to avoid heating of the iron by eddy currents caused by the influence of the alternating current. There are also other special features in the design that reduce the sparking at the commutator, which sparking was for several years the greatest obstacle to the use of alternating-current motors of this kind. In the Westinghouse system the current is taken from the trolley wire at high potential, and is reduced by an auto-transformer on the car. This auto-transformer is connected with an induction regulator so arranged that a low voltage can be supplied to the motor in starting or for slow running, and this voltage increased to increase the speed. There is thus no need to reduce the trolley voltage by wasting part of it in a rheostat, as is the case with direct-current motors; and the efficiency during acceleration is, therefore, higher with this alternating system than with the direct current. Several other single-phase railway motors are also being worked out at the present time, including that of the General Electric Company.

Alternating-Current Motor Advantages. There are two great advantages secured by the use of an alternating-current railway motor. The first is a reduction in investment and operating expenses by doing away with substations containing rotary converters. Such substations are necessary on long lines of railway operating with direct-current motors. The second advantage is that, owing to the fact that a high tension current can be used on the trolley wire and reduced by a transformer on the car, the difficulties of collecting a large amount of energy from a trolley wire are much reduced.

First, in regard to the substations, it will be seen that with the alternating-current motor system, high-tension current can be conducted from the power house to substations along the line which contain nothing but static transformers. Since these transformers have no revolving parts they do not require the constant attendance that a rotary converter does. Furthermore, the investment in rotary converters is entirely dispensed with, and this makes a considerable reduction in the total cost of the distribution plant. With the alternating-current system, current is fed direct to the trolley wire from the secondary terminals of the transformers at the substations.

As regards the advantages of carrying a high voltage on the trolley wire, it will readily be seen that, since the amount of power, or the watts required by a car, is equal to the product of the voltage and current, an increase in the voltage reduces the volume of current necessary. By having high voltage on the trolley wire, even a large car can be operated with a small volume of current, and this current can be taken through an ordinary trolley wheel without difficulty. Where 500 volts is the pressure used on the trolley wire, there is considerable flashing and burning of trolley wheel and wire when large cars and locomotives are run, owing to the heavy current conducted; and this has been one of the principal reasons for the adoption of the third rail instead of the trolley on certain roads. Even with the third rail, the volume of current that must be conducted to large electric locomotives involves some difficulties in the way of heated contact shoes and considerable loss of energy. The use of high voltage on the trolley wire, with transformers on the car to reduce the voltage to a safe pressure for use on the motors, overcomes many of the difficulties that would otherwise be found in the use of electricity for heavy railroad work.

OPERATION.

Power Taken by Cars. The amount of power required in the practical operation of a car depends upon so many variable elements that many of the calculations sometimes given for determining the power required by a car are of little value. The theoretical horsepower required to maintain a car at a certain speed on a level, is evidently the tractive effort in pounds multiplied by the speed in feet per minute and divided by 33,000. What the tractive effort per ton of car will be, depends on the condition of the rail and on several other uncertain factors. For street-railway motor cars, 20 pounds per ton is the usual tractive effort assumed as necessary. A calculation of this kind, however, takes no account of the losses in the motors and gears, nor of the fact that the greater part of the power required to propel a street car in practical service is used in accelerating the car from a state of rest to full speed. In

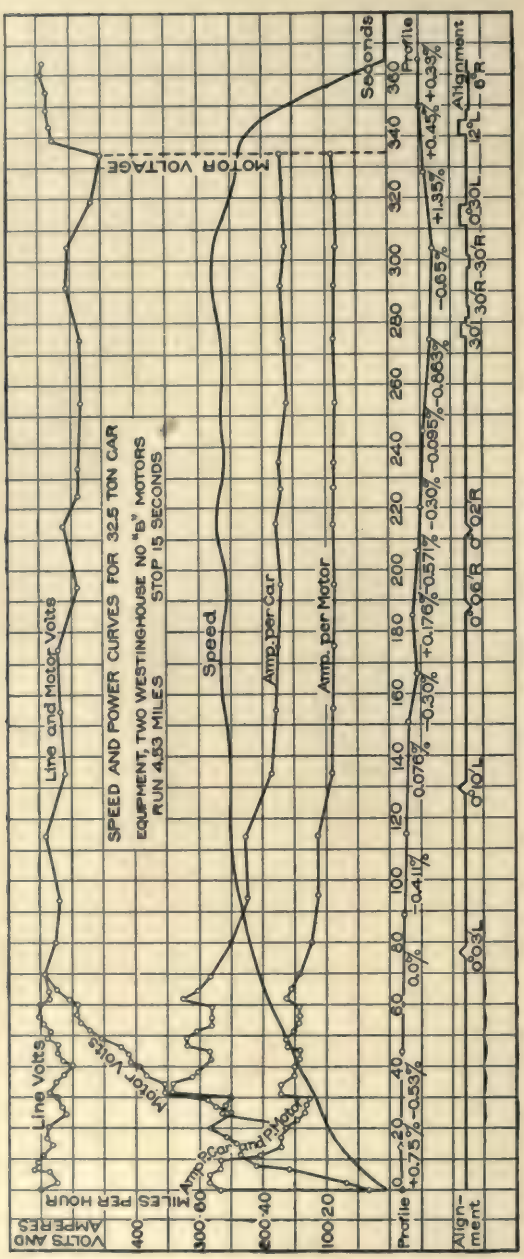
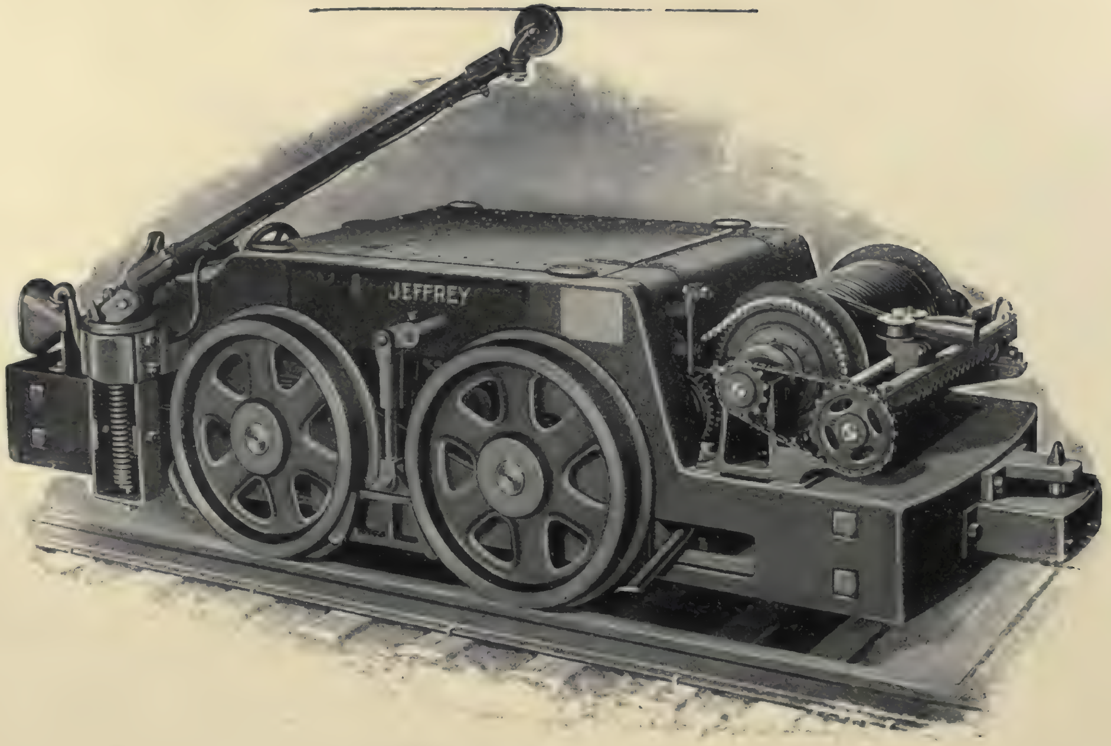


Fig. 93. Plotted Data of Road Test.



JEFFREY 2½-TON ELECTRIC LOCOMOTIVE

With Outside Wheels.

interurban service, of course, the power required in acceleration is not so great a proportion of the whole.

The safest figures to use in engineering calculations as to the amount of power required, are those taken from actual results obtained in everyday commercial service. The power required by an eight-ton car in service in a large city like Chicago, is in the neighborhood of one kilowatt hour per car-mile run. On outlying lines this figure may be reduced to .7 kilowatt hour, and in the down-town districts may run up to 1.5 kilowatt hours per car mile. Double-truck cars in city service, weighing from 20 to 25 tons, take from 2½ to 4 kilowatt hours per car mile at the power station. Interurban cars around Detroit, weighing about 32 tons, in interurban service, making 25 miles per hour, including stops, in level country, and geared to 43 miles per hour, take about 3 kilowatt hours per car mile at the power station. However, interurban railway conditions are extremely variable.

The reports of several Indiana electric railways show an average power consumption of 1.48 kilowatt hours per car mile for city cars and 5.18 kilowatt hours for interurban cars, including line and distribution losses.

An interurban car weighing 31½ tons and equipped with two 150 horsepower motors, on a test run of 50 miles at an average speed of 39 miles per hour consumed 2.20 kilowatt hours per car mile. This car made 18 stops. A similar car under the same conditions made the same run at an average speed of 26 miles per hour with 44 stops, consumed 2.44 kilowatt hours and a third car, making 12 stops and at a speed of 33 miles per hour, consumed 2.10 kilowatt hours per car mile. These individual car test figures are from measurements taken at the car and do not include line losses.

Road Tests of Electric Cars. Of late considerable attention has been given to making road tests of electric cars. The results of the tests are usually plotted in the form shown in Fig. 93. Time is plotted horizontally in seconds, while volts, amperes, speed and per cent grade are plotted vertically. The diagram referred to is the result of a continuous run of 6 minutes of a 32.5 ton car equipped with two motors. The line voltage, motor consumption and other readings may be obtained for any instant of time. The acceleration in miles per hour per second may be obtained by noting the increase in height of the speed curve in one second. In making such a test the necessary instruments, voltmeters, ammeters, wattmeters and speed indicators are mounted direct on the car and are read at intervals of a few seconds.

The curve of motor consumption gives an idea of the abnormal current required to get the car under headway.

Economy in Power. As already stated, a large part of the energy taken by a car in city service is used in accelerating the car. Much of this energy must be destroyed or used up in the brake shoes at the next stop. The energy stored up in a car by process of acceleration is represented by the formula:

$$\text{Energy in ft. lbs.} = \frac{\text{Mass in lbs.} \times (\text{Velocity in ft. per sec.})^2}{2},\ \text{which}$$

is the formula for kinetic or live energy, the derivation of which is found in any Instruction Paper on Mechanics. In performing any given schedule with frequent stops, the more rapid the acceleration the lower the maximum speed required to make the schedule, and the less the energy required in acceleration. For city street and elevated service, therefore, rapid acceleration and low maximum speeds are desirable because not only more economical but safer.

For economical operation with any given equipment and schedule, it is important to use as much of the energy stored up in the car as possible, before wasting it by applying the brakes. Motors are built of a size to yield the large horsepower required in acceleration, and consequently are lightly loaded when operating the car at maximum speed. To economize in power, current should be shut off as soon as possible after the car has attained full speed; and the car should be allowed to drift without current as long as possible before the brakes are applied. In this way the energy stored in the car will propel it at nearly maximum speed for a considerable distance between stops; there will be the smallest possible waste of energy in the brake shoes; and the losses of energy which take place when the current is in the motors will be prevented as far as possible. Practical tests as well as theoretical calculations show a possibility of very material saving in energy in the operation of an electric railway car or train, by the observance of this simple rule of drifting as much as possible and using the brakes as little as possible. Whatever energy is used up in the brake shoes is necessarily wasted. The smaller this waste can be kept while performing a given service, the greater the economy secured.

Cost of Power. The reports of 85 per cent of the railway power generating stations in Indiana show the average cost at the station per kilowatt hour to be .755 cent. This was divided as follows: Fuel .526 cents, labor .158 cents, lubricants and miscellaneous supplies .032 cents, repairs .039 cents. The lowest cost reported was .505 cents.

During 1901 the average cost of power generated at the power house of the Indiana Union Traction Company was .443 cents per kilowatt hour at the switchboard. Distributed from the substations it was .765 cents per kilowatt hour. Natural gas was used for fuel. On occasions when this failed, coal at $1.50 per ton was burned.

Sliding and Spinning Wheels. In accelerating a car, however, there is no economy in turning on current so rapidly as to spin the wheels. As mentioned in the section on "Brakes," the tractive effort between wheels and rails falls off about two-thirds when the wheels begin to slip; and this slipping of wheels, therefore, reduces the chance of securing the acceleration which is possible. For the same reason, in making emergency stops either by the use of brakes or by reversing the motors, care should be taken not to slide the wheels, as by so doing the time required to stop the car is much increased.

In the ordinary straight air-brake equipment used on heavy electric cars, there is much higher pressure carried in the storage reservoir than it is permissible to turn into the brake cylinder, since, if the full pressure were turned into the brake cylinder, it would result in sliding of the wheels—which, it has just been shown, is something to be avoided, not only on account of making flat spots on the wheels, but also because of the reduction in the braking force as soon as the wheels begin to slide. An experienced motorman can tell from the feeling of the car when the wheels are sliding, and will instantly release the brake sufficiently to allow the wheels to begin to revolve as soon as he notices that this has taken place.

The friction between brake shoes and car wheels decreases as the speed increases. A certain pressure applied to the brake shoes upon a car running 50 miles per hour, therefore, exerts much less retarding force than the same pressure at ten miles per hour. In order to give the same braking or retarding force at higher speeds, the brakes must be applied harder than at the lower speeds. If they are applied at the maximum pressure possible without sliding the wheels at higher speeds, it is evident that this pressure must be reduced as the speed of the car is reduced, or the wheels will be "skidded." In the Westinghouse high-speed automatic air brake used on steam roads, this reduction of pressure is automatically accomplished.

TESTING FOR FAULTS.

Bond Testing. It is important to test the conductivity of rail bonds from time to time in order to determine if they have deteriorated so as to reduce their conductivity and introduce an unnecessary amount of resistance into the return circuits. One way of doing this is to measure the drop in potential over a bonded joint as compared with the drop in potential of an equal length of unbroken rail. To do this, an apparatus is employed whereby simultaneous contact will be made bridging three or more feet of rail and an equal length of rail including the bonded joint, as shown in Fig. 94, which illustrates the connections of a common form of apparatus where two milli-voltmeters are employed that measure the drop in voltage of the bonded and unbonded rail simultaneously. If the current flowing through the rail due to the operation of the cars were constant, of course one milli-voltmeter might be used, being connected first to one circuit and then to the other. The current in the rail, however, fluctuates rapidly, so that two instruments are necessary for rapid work. The resistance of the bonded joint is usually considerably more than that of the unbroken rail, and the milli-voltmeter used to

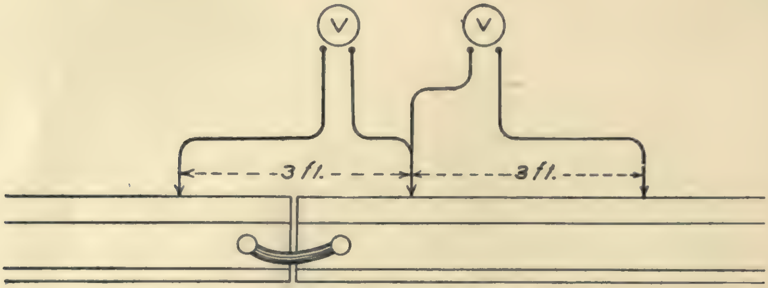


Fig. 94. Bond Testing.

bridge the joint consequently need not be so sensitive as that bridging the unbroken rail.

In another form of apparatus, a telephone receiver is used instead of the milli-voltmeter, the resistance of a long unbroken rail being balanced against that of the bonded joint, as in a Wheatstone bridge, until, upon closing the circuit, these two resistances when balanced give no sound in the telephone receiver.

Bond tests of this kind can be made with satisfaction only when a considerable volume of current is flowing through the rails at the time of the test, because the drop in voltage is dependent on the current flowing, and in any event is small. It has sometimes been found necessary or advisable to fit up a testing car equipped with a rheostat which will itself use a considerable volume of current, so as to give a current in the rail which will give an appreciable drop of potential across a bonded joint. Some of the latest forms of testing cars carry motor generators which will pass a large current of known value through a bonded joint, and so cause a drop of potential across the joint large enough to be easily measured.

Motor-Coil Testing. Testing for faults in the motor armature and field coils is done in a great variety of ways. The resistance of these coils can be measured by means of a Wheatstone bridge employing a telephone receiver in place of the galvanometer used in such bridges in laboratory practice; but other less delicate tests are also in use.

Another method is to pass a known current through the coil to be tested and to measure the drop in the voltage between the terminals of the coil, the voltage divided by the current equaling the resistance.

A simple method, and one which involves no delicate instruments, has lately been introduced into railway shop practice very successfully. This is known as the *transformer test* for short-circuited coils. It requires an alternating current which can easily be supplied either by a regular motor generator or by putting collecting rings onto an ordinary direct-current motor and connecting these rings to bars of opposite polarity on the commutator.

The method of testing for short-circuited armature coils employed in the shops of the St. Louis Transit Company is indicated in diagram in Fig. 95. A core built up of soft laminated iron is wound with 28 turns of No. 6 copper wire. This coil is supplied with alternating current from a 110-volt circuit. The core has pole pieces made to fit the surface of the armature. When one side of a short-circuited coil in the armature is brought between the pole pieces of this testing transformer, as in Fig. 95, the short-circuited armature coil becomes like the short-circuited secondary of a transformer, and a large current will flow in it. This current will in time manifest itself by heating the coil; but it is not necessary to wait for this, as a piece of iron held over that side of the coil not enclosed between the pole pieces, as indicated in Fig. 95, will be attracted to the face of the armature if held directly over the coil, but will be attracted at no other point.

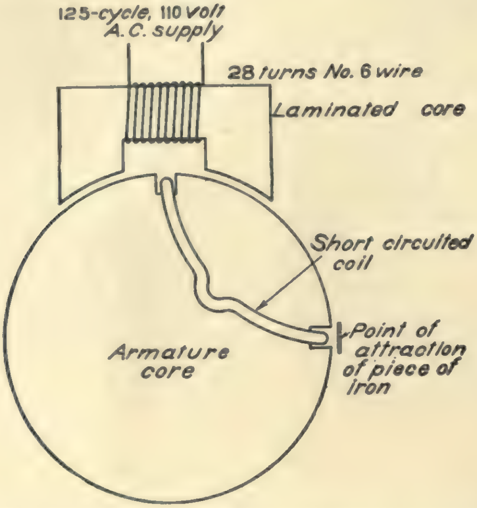


Fig. 95. Method of Testing for Short-circuited Armature Coils.

This testing can be done very rapidly, and does not require delicate instruments or skilled operators.

Tests for short circuits in field coils can be made in a similar manner, by placing the coils on a core which is magnetized by alternating current. The presence of a short circuit, even of one convolution of a field coil, will be apparent from the increase in the alternating current required to magnetize the core upon which the field coil is being tested.

The insulation resistance of armatures and fields is frequently tested by means of alternating current, about 2,000 volts being the common testing voltage for 500-volt motor coils. One terminal of the testing circuit is connected to the frame of the motor, and the other to its windings. Any weakness in the insulation insufficient to withstand 2,000 volts will, of course, be broken down by this test. Alternating current is generally used for such tests because it is usually more easily obtained at the proper voltage, as it is a simple matter to put in an alternating transformer which will give any desired voltage and which can be controlled by a primary circuit of low voltage.

Open circuits in the armature can be easily detected by placing the armature in a frame so that it can be rotated, the frame being provided with brushes resting 90° apart on the commutator. If either an alternating or direct current be passed through the armature by means of these brushes, and the armature be rotated by hand, a flash will occur when the open-circuited coils pass under the brushes. A large current should be used.

The tests just mentioned are among the best of the methods used by electric-railway companies for systematic work in the location of certain classes of faults. A large number of other methods of testing have also been evolved.

The following are some of the most common faults experienced with electric railway car equipments:

Grounds. As one side of the circuit is grounded, any accidental leakage of current from the car wiring or the motors to ground will cause a partial short circuit. Such a ground on a motor will manifest itself by blowing the fuse or opening the circuit breaker whenever current is turned into the motor. In case the fuse blows when the trolley is placed on the wire and the controller is off, it is a sign that there is a ground somewhere in the car wiring outside of the motors. Moisture and the abrasion of wires are the most common causes of grounds in car wiring. In motors, defects are usually due to overheating and the charring of the insulation.

Burn-Outs. Burning out of motors is due to two general causes: First, a ground on the motor, which, by causing a partial short circuit, causes an excessive current to flow; second, overload-ing the motor, which causes a gradual burning or carbonizing of the insulation until it finally breaks down.

Short-circuited field coils having a few of their turns short-circuited, if not promptly discovered, are likely to result in burned-out armatures, as the weakening of the field reduces the counter-electromotive force of the motor, so that an abnormally large current flows through the armatures. Cars with partially short-circuited fields are likely to run above their proper speed, though, if only one motor on a four-motor equipment has defective fields, the motor armature is likely to burn out before the defect is noticed from the increase in speed.

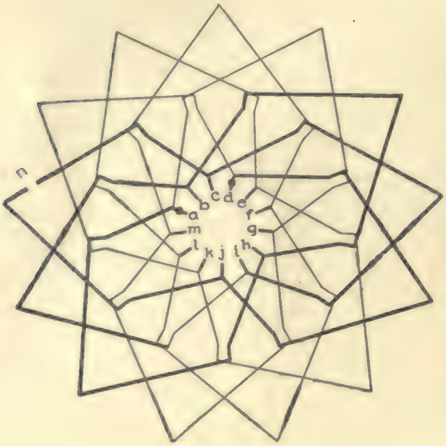


Fig. 96.

Defects of Armature Windings. Defects in armature windings probably cause one-third the maintenance expenses of electrical equipment of cars. Almost all repair shops have men continually employed in repairing them. The most frequent trouble with armatures is through failure of the insulation of the coils and consequent "grounding." This term is used in connection with armatures and fields and other electrical apparatus where a direct path exists to ground. As the armature core is electrically connected to the ground through its bearings and the motor casing, a break down of the insulation of the coils in the slots permits the current to pass directly to ground. This shunts the current around the fields and an abnormal current flows because of their weakness. The circuit breaker or fuse is placed in circuit to protect the apparatus in such an emergency, but usually before such devices break the circuit, several of the coils of the armature are burned in such a manner as to make their removal necessary. The coils are so wound on top of one another that in order to replace one coil alone, one-fourth of the coils of the armature must be lifted.

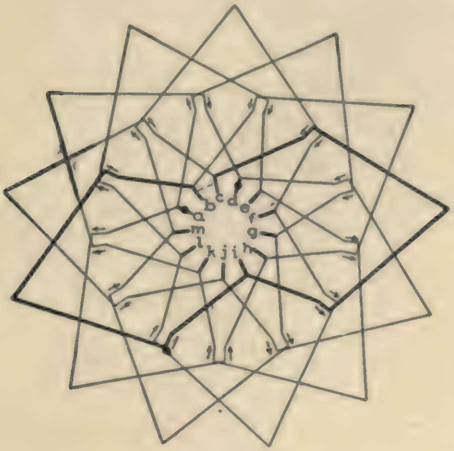


Fig. 97.

With the armature of No. 1 motor grounded the car will not operate and if the resistance points be passed over, the fuse will usually blow. When No. 2 motor is grounded the action of No. 1 motor is not impaired and this latter motor will pull the car until the controller is thrown to the multiple position. But if the motors are thrown in multiple, the path through the ground of No. 2 motor shunts motor No. 1. A study of Fig. 18 will make this evident.

Next to grounding, open circuits are the most serious defects of armatures. These are usually caused by burning in two of the wires in the slot, or where they cross one another in passing to the commutator. Sometimes the connections where the leads are soldered to the commutator become loose.

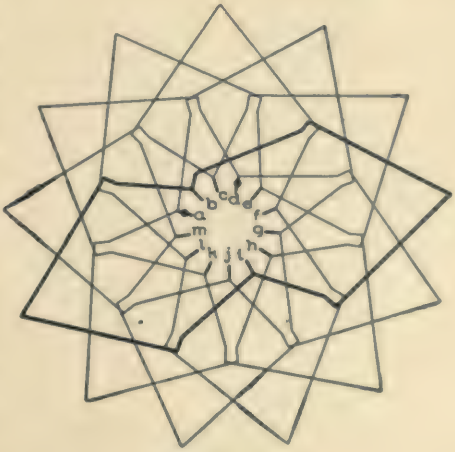


Fig. 98.

The effect of an open circuit is shown in Fig. 96. The circuit is open at n. The brushes are on segments *a* and *d*. By tracing out the winding it will be found that no current flows through the wires marked in heavy lines. Whenever segments *c* and *d* are under a brush the coil with the open circuit is bridged by the brush and current flows as in a normal armature. As segment *c* passes out from under the brush the open circuit interrupts the current in half the armature and a long flaming arc is drawn out.

In Fig. 97 is shown the result of a short circuit between two coils. The short circuit is at *b*, *c*, the two leads coming in contact with each other when they cross. The effect is to short-circuit all of the winding indicated by the heavy lines.

Mistakes in Winding Armatures. The armature winder is given very simple rules as to how to wind the armature, but the great number of leads each to be connected to their proper commutator segment sometimes so confuse him that misconnections are made. The effect of getting two leads crossed is shown in Fig. 98. The leads to segments *b* and *c* from the right are shown interchanged This short-circuits the coils shown in heavy lines. The abnormal current resulting in these would usually cause them to burn out.

Fig. 99 shows the results of placing all of the top leads or all of the bottom leads one segment beyond the proper position. This causes the circuit starting from *a* and traveling counter clockwise around the armature to return on segment *m* instead of on segment *b* as is the case in Fig. 97.

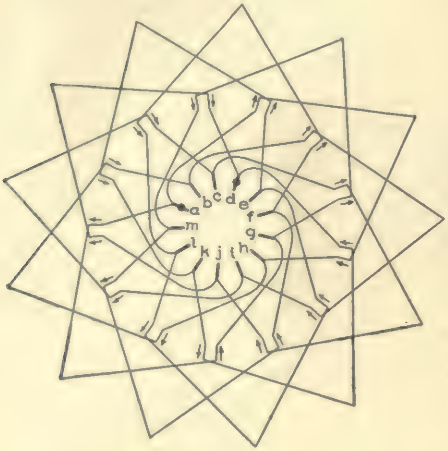


Fig. 99.

The only result of such connections is to change the direction of rotation of the armature. It may be noticed by comparing the two figures that with the positive brush on segments *a* the arrows show the currents to be in opposite directions in coils similarly located with reference to the position of the brushes Some armatures are intended to be wound as in the last case mentioned.

Sparking at the Commutator. As railway motors are made to operate, and usually do operate, almost sparklessly, sparking at the brushes may be taken as a sign that something is radically wrong.

The pressure exerted by the spring in the brush holder may not hold the brush firmly against the commutator.

If brushes are burned or broken so that they do not make good contact on the commutator, they should be renewed or should be sandpapered to fit the commutator.

A dirty commutator will cause sparking.

A commutator having uneven surface will cause sparking, and should be polished off or turned down.

Sometimes the mica segments between commutator bars do not wear as fast as the bars and when this is the case, the brushes will be kept from making good contact when the commutator bars are slightly worn. The remedy is to take the armature into the shop, and groove out the mica between the commutator bars for a depth of about $\frac{1}{64}$-inch below the commutator surface.

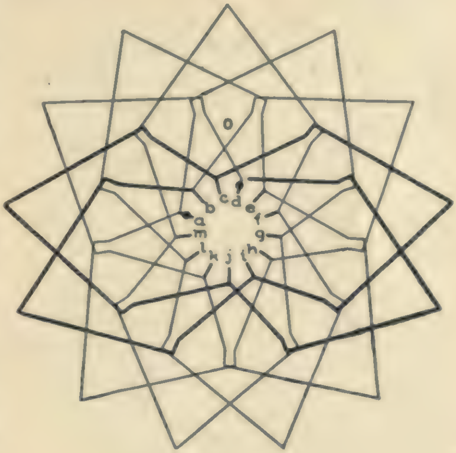


Fig. 100.

A greenish flash which appears to run around the commutator, accompanied by scoring or burning of the commutator at two points, indicates that there is an open-circuited coil at the points at which the scoring occurs as in Fig. 100.

The magnetic field may be weakened by a short circuit in the field coils, as before explained, and this may give rise to sparking.

Short circuits in the armature may give rise to sparking, but will also be made evident by the jerking motion of the car and the blowing out of the fuse.

Failure of Car to Start. The failure of the car to start when the controller is turned on may be due to any of the following causes:

Opening of the circuit breaker at the power house.

Poor contact between the wheels and the rails owing to dirt or to a breaking of the bond wire connections between the rail on which the car is standing and the adjacent track.

One controller may be defective in that one of the contact fingers may not make connection with the drum. In this case try the other controller if there is another one on the car.

The fuse may be blown or the circuit breaker opened. The occurrence of either of these, however, is usually accompanied by a report which leaves little doubt as to the cause of the interruption in current.

The lamp circuit is always at hand for testing the presence of current on the trolley wire or third rail. If the lamps light when the lamp circuit is turned on, it is a tolerably sure sign that any defect is somewhere in the controllers, motors, or fuse boxes, although in case the cars are on a very dirty rail enough current might leak through the dirt to light the lamps, but not sufficient to operate the cars. In such a case, the lamps will immediately go out as soon as the controller is turned on. Ice on the trolley wire or third rail will have the same effect as dirt on the tracks.

LOCATING DEFECTS IN MOTOR AND CONTROLLER WIRING.

Defects in the wirings are those due to (1) open circuits, (2) short circuits. Open circuits make themselves evident by no flow of current, short circuits usually by a blowing of the fuse or opening of the breaker. The point of the short circuit or "ground" can be located roughly by noting on what point the fuse is blown. Accurate location can be made by cutting out the motors, disconnecting, etc., according to directions in the following pages. The tests outlined apply particularly to the K type of controller with two-motor equipment.

OPEN-CIRCUIT TESTS.

No current:
    On 1st point,
        Open circuit but not located.
    On 1st point multiple,
        Motors most probably O. K.

On series-resistance points after trying 1st point multiple,
Open circuit outside controller and equipment wiring.

With an open anywhere between trolley and ground no current will flow on the first point. Opens are most likely to occur in the motors and these may be tested first. However, as will be explained later, one open in an armature will not stop the current. To test the motors open the breaker and put the controller on the first point multiple. Then flash the breaker quickly. Current flowing indicates that one or the other of the motors has an open circuit. In the series position this open prevented the flow but in multiple the current flows through the other motor. Which one is at fault can be quickly determined by returning the controller to the off position and cutting out one or the other of the motors by means of the cut-out switch and then trying for current. The car can in any event be run on the remaining motor. On returning to the shop the open can be determined definitely by the use of the lamp bank.

But should no current flow when the breaker is flashed on the 6th point it is reasonable to presume that the motors are O. K. and that the open is elsewhere. The ground for such a supposition is that as there is a path through each motor normally, there would necessarily be an open in each one to stop the current. It is hardly probable that such a coincidence would occur.

After failure to find fault with the motors, doubt as to the resistance may be removed. The controller should be placed on progressive series-resistance points and the breaker flashed on each one. If current is obtained on any point, the open is in the resistance or the resistance lead just behind the one being used. Special care should be used to flash the breaker quickly for otherwise the fuse may be blown.

The tests indicated are sufficient for the motors, controllers and resistance wiring. If no current is obtained on either of them, the trouble is evidently caused by a bad rail contact, ground wire off if both motors are grounded through the same wire, an open in the blow-out coil, at the lightning arrester, circuit breaker or on top of the car.

None of the tests applied locate the open definitely, but this can easily be done in the shop or wherever a lamp bank is at hand. Connect one terminal of the lamp bank to the trolley just behind the circuit breaker and the controller on the 1st point series, then with the other terminal begin at ground and trace backwards up the circuit until the lamps fail to light. The path in a K type of controller is readily traced with the help of Fig. 22.

SHORT-CIRCUIT TESTS.

The location of short-circuits is much more tedious. The blowing of the fuse or opening of the breaker will locate them as shown below. The separate tests can then be followed until location is definite.

These tests it must be kept in mind are more especially adapted to cases on the road or where no facilities for testing are at hand.

Rather than blow fuses as frequently as indicated it would in most cases be better to place a lamp bank across the open circuit breaker and note the flow of the current by the lights.

Fuse Blows:

- I. When overhead is thrown on may be due to:
    1. Grounded controller blow-out coil.
    2. Grounded trolley wire or cable.
    3. Grounded lightning arrester.
- II. On first point:
    1. Grounded resistance near R 1.
    2. Grounded controller cylinder.
    3. Bridging between the insulated sections of cvlinder.
- III. Near last point series:
    1. Grounded resistance near R 3, R 4 and R 5.
    2. No. 1 motor grounded.
- IV. Near last point multiple:
    1. No. 2 motor grounded.
    2. Bridging between lower sections of cylinder.
    3. Armature defective.

CASE I.

Fuse Blows when overhead is thrown on:

1. Grounded controller blow-out coil.
2. Grounded trolley wire or cable.
3. Grounded lightning arrester.

The blowing of the fuse immediately on closing the overhead switch or circuit breaker, when the controller is on the off position, indicates that the fault exists somewhere between the overhead and the upper or trolley finger of the controller.

Should the defect occur during a thunderstorm, it may be presumed at once that lightning has grounded the blow-out coil of the controller.

CASE II.

Fuse Blows on first point:

1. Grounded resistance near R 1.
2. Grounded controller cylinder.
3. Bridging between sections of cylinder.

When the controller is on the first point all of the wiring of the system with the exception of the ground wire for No. 1 motor is connected with trolley. But a defect in the wiring beyond the resistance will not show itself on the first point by an abnormal rush of current because the resistance of the rheostats is sufficient to prevent any excessive flow of current.

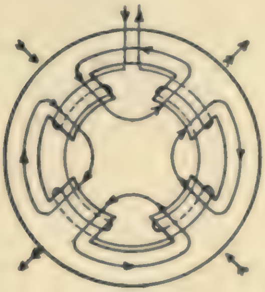


Fig. 101.

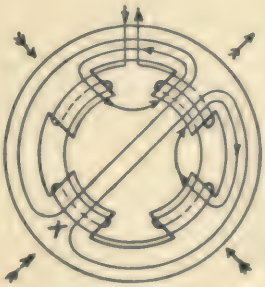


Fig. 102.

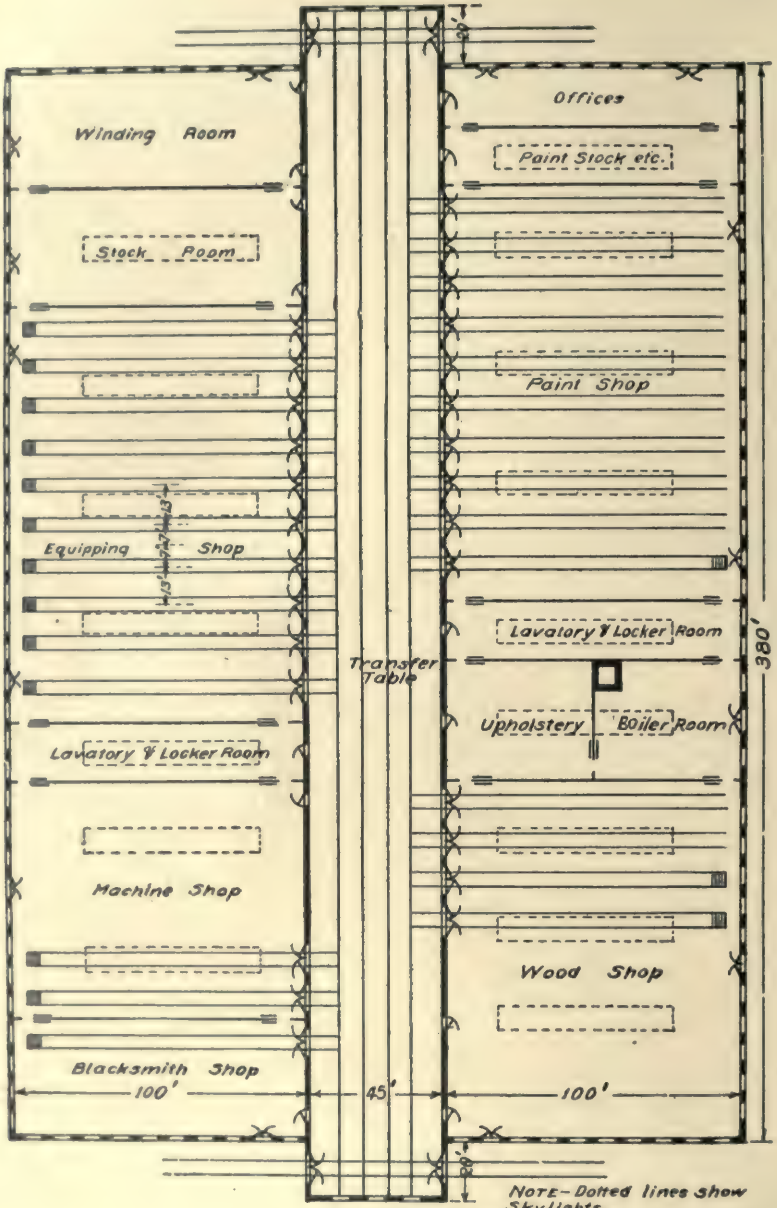
The resistance and leads and the controller cylinder are the only parts to be tested when the fuse blows on the 1st point.

CASE III.

Fuse Blows on 3rd or 4th point:

1. Grounded resistance near R 4 or R 5.
2. No 1 motor grounded.

With either of the above defects the car will most probably refuse to move as the current is led to ground before passing through the motors.



NOTE—Dotted lines show Skylights.
All partitions are of vitrified tile.

Fig. 103. Plan of Car Shop.

No. 1 motor may be tested by cutting it out of service by means of its cut-out switch. If this removes the ground, the motor is at fault.

CASE IV.

Fuse Blows near last point multiple:

1. No. 2 motor grounded.
2. Either armature short-circuited.

The fact that the fuse did not blow on the series positions excludes the resistances and No. 1 motor from investigations for grounds.

Cut out both motors. If the ground still exists the controller is defective If not, the fault may be located in either one of the motors by cutting out first one and then the other.

ARMATURE TESTS FOR GROUNDS.

With a lamp bank at hand tests for grounded armature can be made as follows:

Throw the reverse on center. Attach one terminal of the lamp bank to the trolley. Put the other terminal on the commutator of the armature to be tested. No current shows the armature O. K. If current flows remove brushes and try again, to be certain that the ground is not in the leads.

FIELD TESTS FOR GROUNDS.

Disconnect field leads and put test point of the lamp bank on one side of the terminals. No current indicates that the fields are O. K.

REVERSED FIELDS.

In placing new fields in the shell it often happens that one or more are wrongly connected. Reversed fields make themselves known by excessive sparking at the brushes in each case.

In Fig. 101 all of the fields are connected correctly. The flow of magnetism is in one pole and out of the adjacent one. Some of the magnetism leaks out of the shell and affects a compass held near the outside. The direction taken by the compass needle in the different positions is shown The needle should point in opposite directions over adjacent coils and should lie parallel to the shell in positions half way between two coils.

Figure 102 shows the flow of magnetism when one field is reversed. In such a case the compass will take the position shown. The field marked "X" is the one reversed.

With one reversed field a machine will usually operate, as the magnetism in three of the poles is in the normal direction. But an excessive flow of current that has no effect in turning the armature will take place on that side of the armature next to the reversed field.

CAR REPAIR SHOPS.

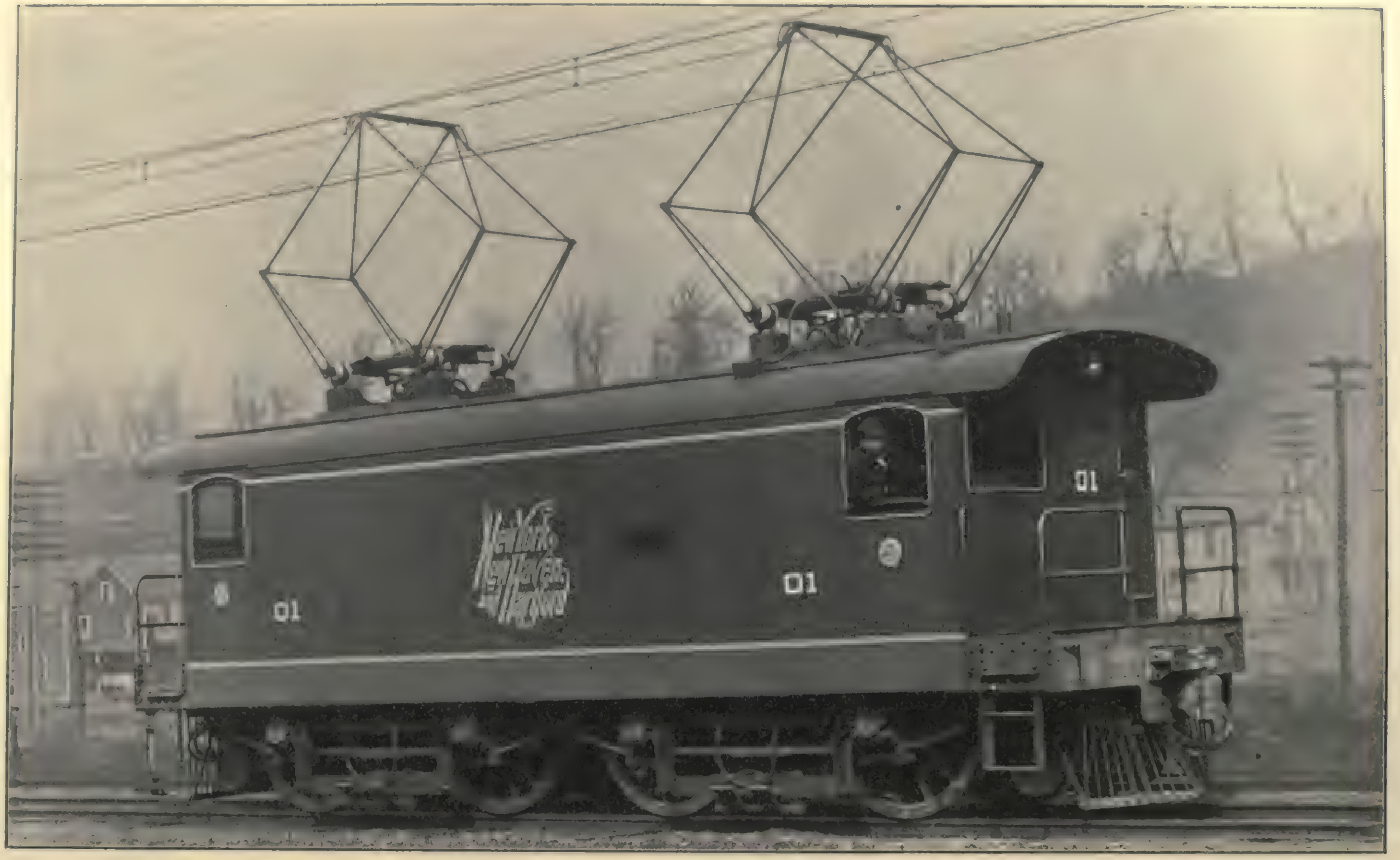
Every electric railway system has a repair shop in which the cars are overhauled. Hardly two shops are built alike. In those shops where only a few cars are cared for, the work is sometimes all done in one room. The shop plan shown in Fig. 103 was presented to the American Railway Mechanical and Electrical Association by W. D. Wright. It contains the idea upon which the larger shops are now being constructed, having a transfer table between the separate departments on either side. In the general design of shops the blacksmith shop, machine shop and truck shop or equipping shop should be close together as a great deal of heavy material is carried between these departments. The paint shop should be separated as much as possible from the other departments in order that flying dust and dirt be avoided. The wood shop may occupy a position at a considerable distance from the other departments as no heavy material is carried from this shop to them.

The tracks of the motor and truck repair shop are usually provided with pits so that trucks and electrical equipment may be repaired and inspected from below. The tracks in shops are usually about 15 or 16 feet between centers. This gives a clearance of about 6 or 8 feet between cars when adjacent tracks are occupied.

A large portion of the work done in the average shop consists of the repairing of trucks and the motors mounted on them. With the smaller car, especially those with single trucks, much of this work is done from the pit below while the trucks are in position under the cars. In this case the armatures are either removed by letting them down with the lower half of the motor shell by means of a pit jack, or the lower half of the armature shell is swung down by the use of a chain and block placed in the car and the armature rolled out on a board.

The trucks of double truck cars are usually taken out from under the car body when repairs are to be made. In this case the motor leads, the sand box connections and the brake rigging are disconnected and the car body either raised or the trucks lowered from it. Several methods of raising the car body are in use. Where no special apparatus is at hand, this is done by means of jacks, hydraulic or mechanical, placed under the side sills of the car near the end to be raised. Sometimes an overhead crane is employed to lift the car body. A special apparatus to raise the body is employed by the St. Louis Transit Company. This consists of four screw jacks located below the floor of the shop. An I-beam extends over the tops of the two located on the same side of the car. The jacks are motor driven by means of one sprocket chain so that they rise at the same speed. When a car is to be raised it is run on the track between the jacks, bars are placed under the car resting across the I-beams and the jacks raise the car off the trucks. The trucks are then rolled out from under the car and the repairs made.

Sometimes, as has been stated, the trucks are dropped from the car body. In this case the car is so placed that the truck rests on an elevator or section of track that drops to the floor below. After the car is blocked up the trucks are dropped and the repairs made. This method is also used in changing wheels in small shops. The old pair of wheels is dropped by a hand-operated drop section of track. A new pair is then elevated into position. This saves jacking up one end of the car.



ONE OF THE SINGLE-PHASE LOCOMOTIVES ON THE NEW YORK, NEW HAVEN & HARTFORD RAILROAD CO.
Note the two pantograph bow trolleys for collecting the current.

THE SINGLE-PHASE ELECTRIC RAILWAY.

In no other line of electrical activity have developments during the last few years been so rapid as in that of electric railway work, and from all indications the limit has not yet been reached.

Until recent years all electric traction has been dependent upon direct current as a motive power. This is due principally to the fact that the series direct-current motor is admirably adapted for such work, and no alternating-current motor had been developed which could be substituted for it. One of the great advantages possessed by the direct-current series motor is its large starting torque, which may be several times greater than that required to propel a car at full speed. This type of motor is also essentially a variable speed machine, and lends itself very well to wide variations in speed control; consequently, for many years, in this country at least, all advance was made along direct-current lines.

The trolley voltage used at first was from 450 to 500 volts, this being supplied directly to the cars by means of a trolley wire, the rails being used for the return circuit. It is evident from the outset that the comparatively low voltage, necessitating as it did a correspondingly large current for a given amount of power, would place a definite limitation on the use of such a system for anything other than purely local distribution. To overcome this difficulty as far as possible, the trolley voltage was gradually raised to 600 or 650. This of course decreased the required current, thus increasing the scope of the system accordingly. The limit of increase of direct-current voltage on the trolley was reached at about this point, and the fact was recognized that some means must be devised for using a still higher voltage, since there are difficulties to increasing the trolley voltage beyond 600 or 700, due to flashing of the motors, which seems to increase directly with the voltage.

It may be mentioned in passing that one prominent electric traction expert has stated that a direct-current trolley voltage of 1500 can be used, but it remains to be proven whether or not he is correct.

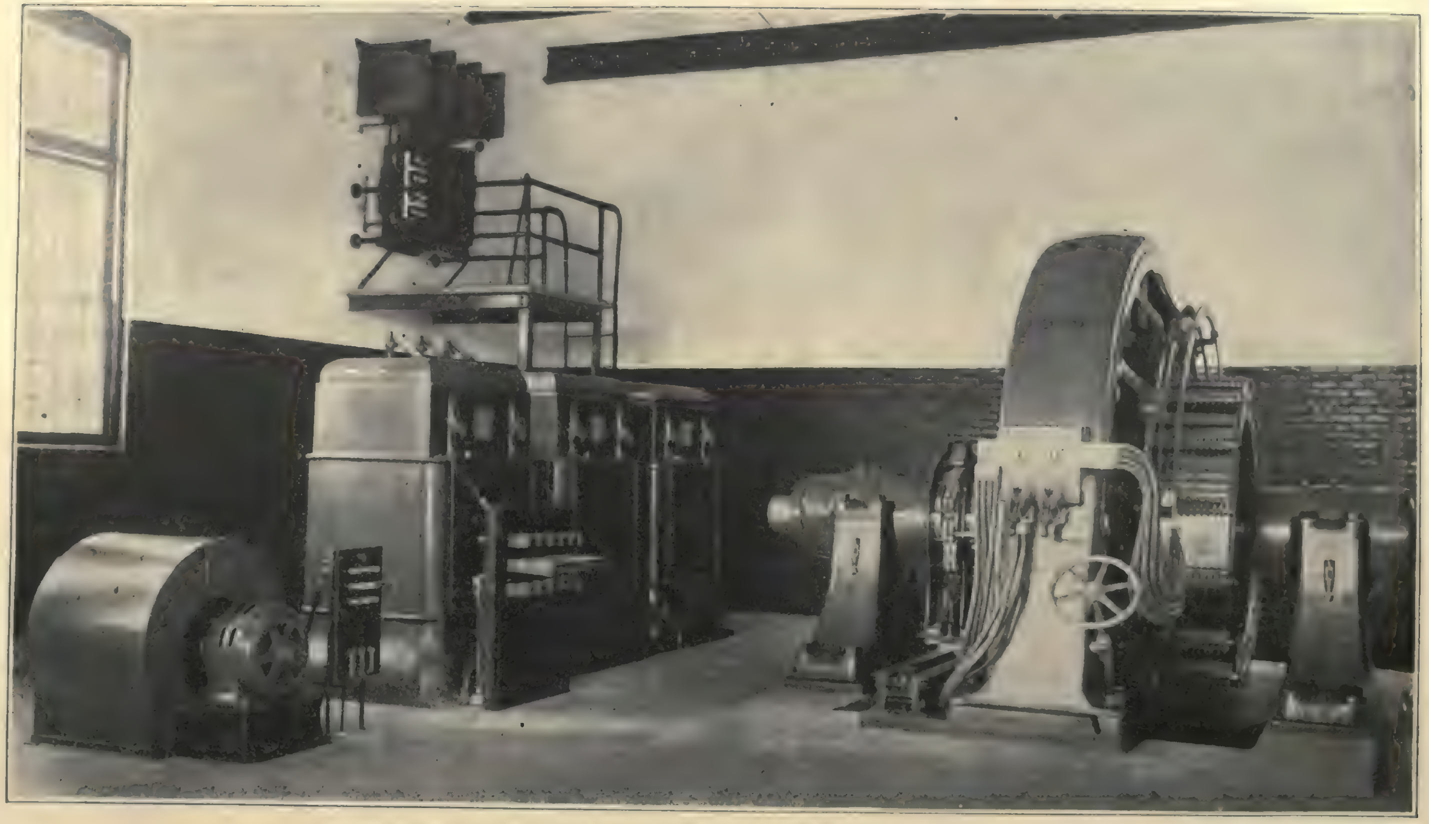
A very satisfactory solution of the problem for large city street railway systems and long interurban roads, consists in the use of a combination alternating-current direct-current system in which three-phase high tension alternating current is generated and distributed on high tension lines to substations along the road. It is here stepped down by means of transformers, and then changed to direct current by rotary converters, and supplied to the trolley wire as direct current at the usual voltage of say 600. This system has many advantages, as there is but small loss in the high-tension lines, and these lines can be made comparatively small, thus effecting a considerable saving in investment for copper.

The above mentioned system of distribution is very generally used, and has been found quite satisfactory. The substations can be located at frequent intervals, and the distance that the 600-volt current must be conducted to supply the cars is not great. By this means current can be distributed over wide areas with a small loss, where it would be impossible to use the straight direct-current system of distribution.

While, as stated, this furnishes a fairly satisfactory solution of the problem, it is far from perfect, as it necessitates the intervention of the rotary converter substation, in which the investment must be large; and moreover the cost of operation is high, as such a station requires skilled attendance on account of the somewhat intricate nature of the rotary converter. The ideal system, therefore, is one which does away altogether with the use of direct current, the power being generated, distributed, and utilized by the motors, as alternating current.

Three-phase induction motors have been used quite extensively and with considerable success in Europe for many years past. The three-phase motor, however, is not entirely adapted for railway work, since it possesses the characteristics of the shunt rather than of the series motor, being a constant speed, not a variable speed machine. Moreover, two trolley wires are necessary instead of one, and still another disadvantage consists in the low power-factor of the three-phase induction motor at starting.

The recent application of the single-phase alternating current to railway work has opened up a new field, which bids fair to supplant all other forms of distribution to a great extent at least, and



INTERIOR OF SUB-STATION SHOWING ROTARY CONVERTER AND TRANSFORMERS.
The three-phase current is delivered to the transformers where it is stepped down to the voltage required for the rotary converter. In this machine it is transformed to direct current and delivered to the trolley wire.

it is impossible to predict at the present time just what its limitations may or may not prove to be. This has been made possible by the development of a *practical commercial* single-phase motor, which permits of the use of alternating current on the trolley wire with all its advantages, and yet sacrifices few, if any, of the advantages of the direct-current series motor on the car.

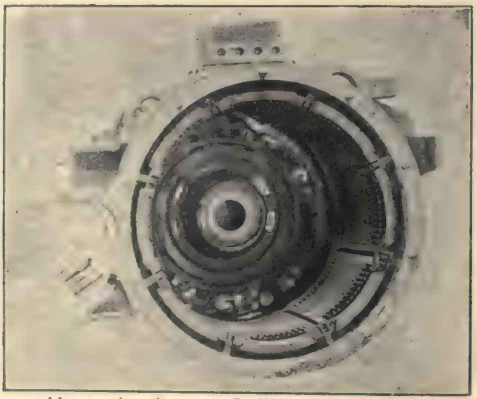
This motor, which is the latest and most important development in the electric railway field, is of the series commutator type, and does not differ in principle from its direct-current contemporary. It is called the *commutator type single-phase* motor, and is the one type of alternating-current motor which has the same desirable characteristics for railway work as the direct-current series motor.

Compensating Alternating-Current Railway Motor.

At first thought it may seem strange that a motor built fundamentally on the same lines as a direct-current machine would operate on an alternating current, as it might appear that the motor would tend to turn first in one direction and then in the opposite direction with no resultant motion. This, however, is not the case, because the direction of rotation of a motor depends upon the relative direction of its field and armature currents. If now the field were maintained in a constant direction and the armature supplied with alternating current, then the tendency would be to rotate first in one direction and then in the other, it is true, but as a matter of fact the alternating current is supplied to the field in series with the armature, so that when the direction of current in the armature changes it also reverses in the field. The result is that the relative direction of current in the field and armature is constant and the motor has, therefore, a tendency to turn continuously in one direction as long as the alternating-current power is supplied.

This being true, the question may arise as to why the single-phase motor was not brought to the front for railway work long ago. The answer is that there were certain inherent difficulties to be overcome, and the development of the single-phase motor has been simply the removal of these difficulties, rather than the design of an entirely new type of machine.

The most serious obstacle to overcome is the sparking at the commutator, due to the fact that when the terminals of a coil are bridged by a brush, the coil acts like the short circuited secondary of a transformer of which the field winding constitutes the primary. Also there is an iron loss due to the alternating magnetic flux through the magnetic circuit; while another objectionable feature is the counter E.M.F. induced in the field coils.



Alternating-Current Railway Motor Field.

In order that it may overcome these difficulties, to some extent, at least, the single-phase motor presents certain modifications from the direct-current type, in that it has more field poles, and the entire magnetic circuit of field frame, cores, and pole pieces, is carefully laminated. The number of commutator segments is also increased, thus reducing the number of armature turns per coil, and there are special features introduced to prevent sparking, such as compensating windings which neutralize the effect of armature distortion; the use of narrow brushes; a type of armature winding which gives a low reactance per coil; the use of high resistance leads between the armature coils and commutator segments, etc.

The single-phase motor is then a refined and highly perfected type of direct-current motor, and this explains the fact that it will operate on either alternating- or direct-current circuits. In fact some claim that it will operate even more efficiently on direct current than the regulation direct-current motor itself.

Single-Phase Armature, Unmounted.

The field for which the single-phase motor seems particularly adapted is that of heavy service and interurban work, where it has many distinct advantages, among which may be mentioned the following:

The alternating current on the trolley allows the use of a high voltage and correspondingly smaller current, which reduces the line loss and permits of the use of smaller wire, which of course means a saving in the investment for copper. Moreover, the difficulty of collecting a large current from the trolley wire is overcome. Rotary converter substations are eliminated, being replaced by simple and cheap transformer substations, which require no attendance. The capacity can be easily increased by merely increasing the number of these transformer substations.

The efficiency of speed control is a point particularly worthy of mention. In direct-current speed control, the series-parallel method is used almost exclusively. This consists of putting the motors in series for low speed and in parallel for high speed. This permits of two, and only two, economical running points; the one at full speed, and the other at approximately half speed. All intermediate points must be obtained by the insertion of dead resistance in which the voltage is simply wasted as heat, thus causing a large loss particularly at starting.

With the single-phase motor the current is supplied to the car with a voltage of say 3300. It is then stepped down by means of transformers on the car to the voltage of the motors, which may be 200 or 250 volts. The speed is, of course, dependent upon the voltage applied to the motors, and this voltage is cut down from the maximum, to obtain various gradations, by means of an induction controller, or by taps from an auto-transformer. Thus the motor takes from the trolley only slightly more power than is actually required to operate it at any given speed, instead of taking full voltage from the line and absorbing part of it in dead resistance.

The effect of electrolysis upon neighboring water pipes paralleling an electric road, which is the cause of so much trouble with direct current, is entirely eliminated, as electrolysis evidently will not take place with alternating current.

Auto Transformer.

In connection with this system a sliding contact device or bow trolley has in many cases been substituted with considerable success for the ordinary current collecting device, or trolley wheel, one advantage of this being that the car can be run in either direction without reversing the contact device. Another very satisfactory form of trolley is of the pantograph type with sliding shoe, shown on the New York, New Haven and Hartford locomotive.

A new form of trolley suspension known as the catenary has been developed to meet the demand for more substantial construction necessitated by the high trolley voltage. This consists of a stranded galvanized steel messenger or supporting cable, from which the trolley wire is suspended at intervals of about 10 feet, thus keeping it at a uniform distance above the track.

The multiple-unit system of control can be used in connection with single-phase motors, this being the scheme which has been in use for a long time on elevated and other roads using direct current, whereby several cars can be operated in a train from a single point, each car being equipped with its individual motor and controlling apparatus. The entire system is then controlled as one unit by a single motorman stationed usually in the front of the first car. This method of control has become of such tremendous importance that any system to which it cannot be applied would be seriously handicapped. Cars equipped with single-phase motors can be operated on either direct-current or alternating-current lines, with high or low tension, with trolley or third rail.

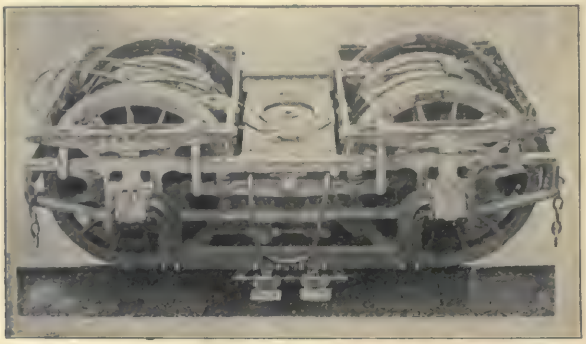
Master Controller Used in Connection with the Multiple-Unit System as Applied to Single-Phase Work.

It must not be supposed, however, that with all the above mentioned advantages, the single-phase system has no disadvantages, as such is not the case. The car equipment, due to the transformers and the nature of the motors, is considerably heavier. The motors themselves are more expensive on account of their special construction. The equipment is not always adapted for operation on existing lines. There is a slight increased "apparent" resistance of the trolley line and a considerable increased "apparent" resistance of the rails, due to reactance caused by the alternating nature of the current. There is also an active electro-motive force between the field coils, which is objectionable, and there is a possibility of interference with neighboring telephone lines. Furthermore, there is slight loss in power in the transformers on the car, while the power-factor of the motors is less than unity.

Summing the matter up as a whole, however, the advantages seem to overbalance the disadvantages, at least for many kinds of work, and it is safe to predict that this new system of operation will have a very wide and increasing application in the near future.

As to the operation of the system in general, the current may be developed by single-phase, two-phase, or three-phase generators, and supplied to the transformer substations just as it was formerly supplied to the rotary converter substations. Only a single phase is used on any section of the trolley line. The voltage on this transmission line will depend upon the existing conditions, and can be figured out like any other problem in power transmission.

Three-phase generators would ordinarily be used, as less copper is required to supply a given amount of power. The common frequency is 25 cycles per second. At the transformer stations, the voltage is then stepped down to that required on the trolley, which may be 2,000, 3,300, 6,600, or even 11,000 volts. While we cannot speak yet of a standard voltage, 3300 seems to be finding considerable favor. The voltage for which the motors are wound is 200 or 250, the General Electric motors using the former voltage, and the Westinghouse the latter. When operating on alternating current the motors are connected in parallel, and when running on direct current they are connected in series. Motors have been constructed from 50 to 225 horsepower, and there is no apparent reason why larger ones could not be made to operate with equal satisfaction.


Truck Complete with Single-Phase Motors and Contact Shoes.

Among the roads in this country which are either using, or planning to use single-phase current, may be mentioned the Ballston-Schenectady line, which was one of the first systems to be equipped and has been in successful operation for some time. This road uses the alternating-current motor developed by the General Electric Co. The motors are adapted for operation on the 2,000-volt alternating-current trolley between cities, and on the standard 600-volt direct current in Schenectady. They are wound for 400 volts, and are operated in series on the 600-volt direct current. The frequency used is 25 cycles. Current is supplied by an overhead trolley, no feeders being used.

Magnetic Speed Indicator.

A second road of importance is one in Georgia between Atlanta and Marietta, which is 15 miles in length. This uses the Westinghouse equipment. The current on the trolley is 2,200 volts and 25 cycles. It is transmitted at a voltage of 22,000.

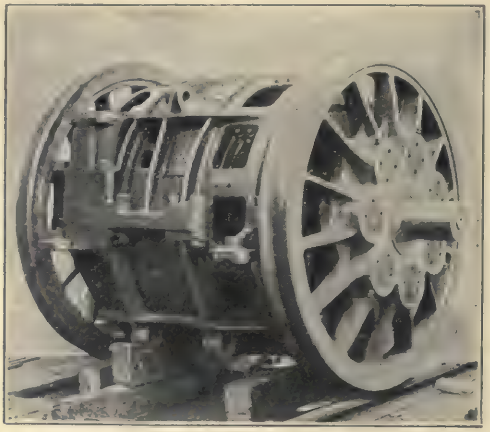
Another road of importance is the Indiana and Cincinnati interurban line, 41 miles in length, which has been in operation on regular schedule since July 1st, 1905. For 37 miles the road is operated from alternating current, and for 4 miles, from direct current. Four 75-horse power motors per car are used, capable of a maximum speed of 65 miles per hour.

Armature Quill.

The Bloomington, Pontiac and Joliet Electric Railway is a single-phase road equipped with General Electric apparatus, and has maintained a regular schedule over a distance of more than 10 miles since March, 1905.

The plans are now being laid for a single-phase road, which will run south from Spokane, Washington, a distance of 150 miles. The current on the transmission line is 45,000 volts, which is stepped down to 6,600 on the trolley. The car will be capable of operating on current from a 6,600-volt alternating, a 700-volt alternating, or a 575-volt direct-current supply.

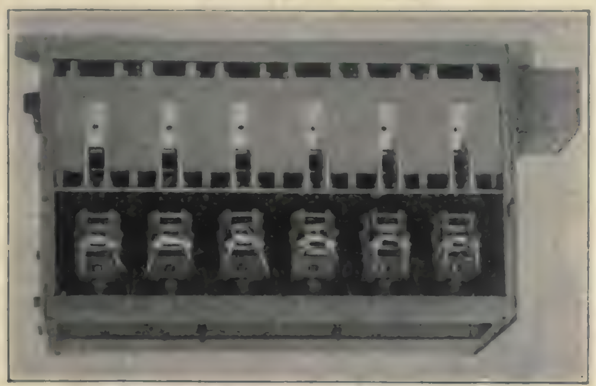
Perhaps the most important move which has been made in the direction of single-phase traction thus far is the decision of the New York, New Haven, and Hartford road to establish a long-distance passenger traffic on the single-phase system. According to the latest plans this road will operate between the Grand Central Depot and Woodlawn, N. Y., over the terminal tracks of the New York Central road, on direct current taken from the trolley. From Woodlawn, N. Y., to Stamford, Conn., the road will be operated on the single-phase system.



A Pair of Drivers with Single-Phase Motor Mounted upon Quill.

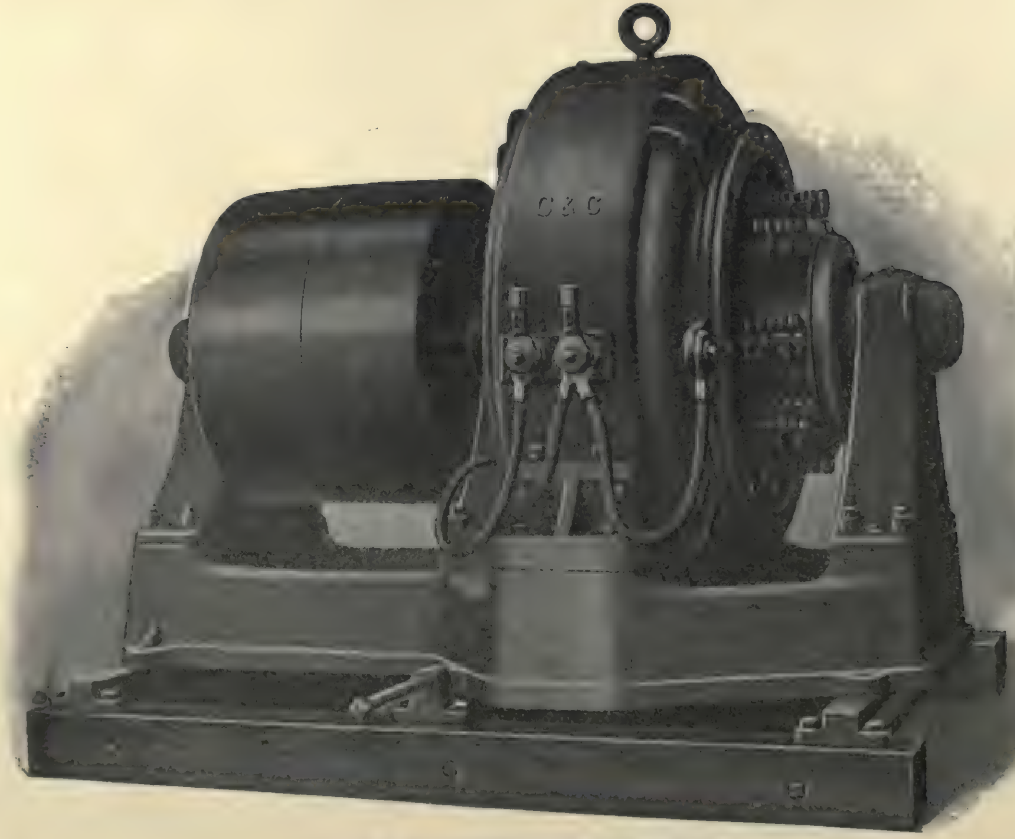
The equipment is being supplied by the Westinghouse Co. The current is generated by revolving-field type turbine-driven alternators. The armatures are designed for either three-phase or single-phase connection. The current is generated at 25 cycles and 11,000 volts, being delivered directly to the trolley, and thence to the cars, without the intervention of any transformers. The double catenary suspension from messenger wires is used to support the trolley. The locomotives are each equipped with four 200-H. P. gearless motors, designed to operate on 235-volt alternating current and 275- to 300-volt direct current.

The armature is not mounted on the shaft direct, but is built upon a quill through which the axle passes with about ⅜-inch clearance all around. There is a flange at each end of the quill from which seven pins project and fit into the hubs of the driving wheels. On the direct-current part of the line, current is delivered to the car through eight collecting shoes from a third rail. On the alternating-current section, current is delivered through two pantograph bow trolleys. On the direct-current section the series-parallel method of speed control is used, current being fed directly to the motors which are connected two in series permanently and the series-parallel control is applied to the motors in groups of two. The alternating-current speed control is accomplished by six taps from an auto-transformer for the corresponding running points. The cars weigh 78 tons and are capable of a speed of 60 to 65 miles per hour. The electro-pneumatic unit-switch type of control is used. At each end of the cab is a master controller from which the main controller is operated. Several locomotives can be operated together on the multiple-unit system, if desired.



Six-Unit Switch Group, Single-Phase System.

The Washington, Baltimore and Indiana single-phase road is the latest in the field, contracts having been placed very recently. The current will be transmitted at 33,000 volts and 25 cycles, then being stepped down to 6,600 volts on the trolley. The road will be 60 miles long and will be equipped with General Electric apparatus. Four 125-H. P. motors capable of operating on either alternating current or direct current will be used, and the cars will be capable of a speed of 60 miles per hour.



300 K.W. THREE-BEARING GENERATOR.

The C and C Electric Company.

TYPES OF DYNAMO-ELECTRIC MACHINERY

DIRECT-CURRENT

INTRODUCTION

Dynamo-electric machinery is the generic name given to the class of machines that employ relative motion between an electric conductor and a magnetic field for the purpose of converting mechanical power into electrical power, or the reverse.

The various types fall naturally under the two main divisions of alternating-current and direct-current machines. Reserving the consideration of alternating-current machines for a later chapter and confining our attention for the present to the direct-current ones, we find that these latter can be further subdivided into generators, motors, dynamotors, motor-generators, and boosters.

Agreeing with the Standardization Rules of the American Institute of Electrical Engineers, the following definitions apply to these five subdivisions of direct-current machines:

1. A *generator* transforms mechanical power into electrical power. Originally the name dynamo-electric machine was used to designate an electric generator. On account of its length, this term was soon shortened to that of dynamo. Recently the name generator has supplanted that of dynamo, it being considered preferable on account of its rather self-evident meaning.

2. A *motor* transforms electrical into mechanical power.

3. A *dynamotor* is a transforming device combining both motor and generator action in one magnetic field, with an armature having two separate windings and independent commutators.

4. A *motor-generator* is a transforming device consisting of a motor mechanically connected to one or more generators.

5. A *booster* is a machine inserted in series in a circuit to change its voltage. It may be driven by an electric motor (in which case it is termed a *motor-booster*) or otherwise.

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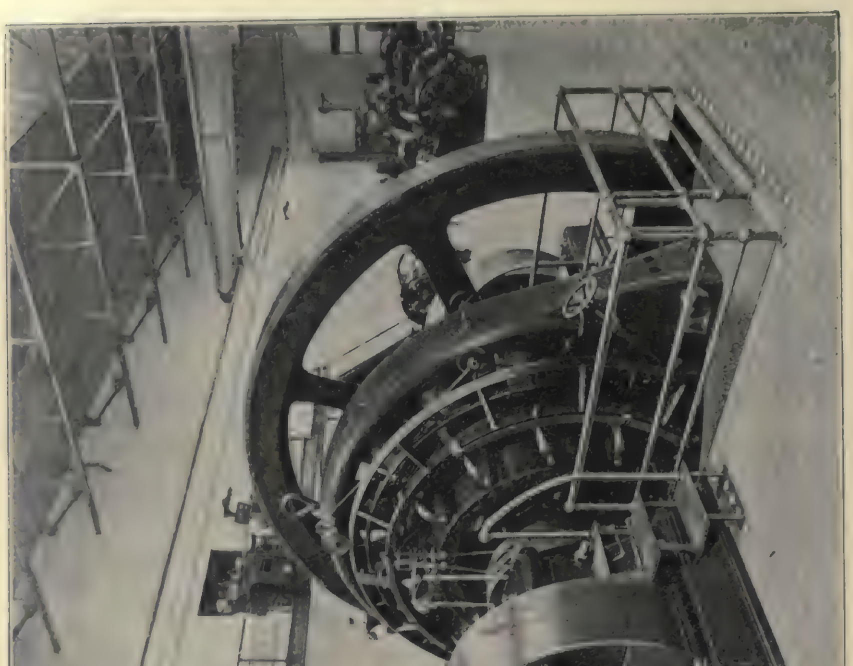

Fig. 1. Allis-Chalmers Type *I* Generator, Driven by an Allis-Chalmers Cross-Compound, Heavy Duty Engine.

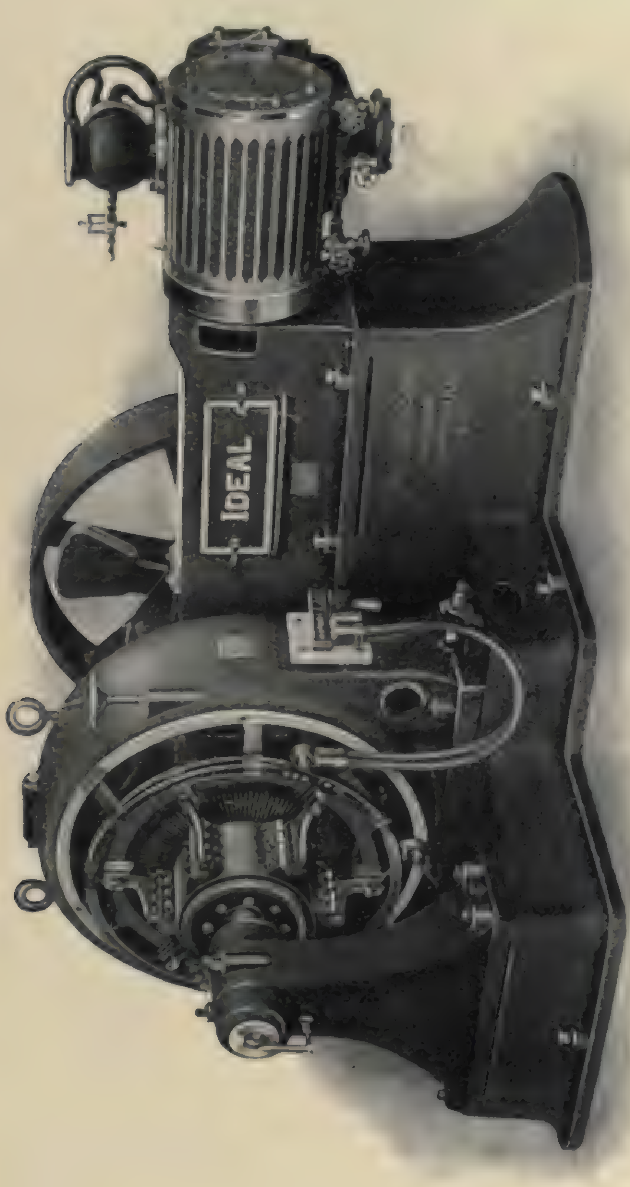

Fig. 2. Direct-Connected Generator for Electric Lighting and Power Purposes.

In order to present the various modern direct-current types in some logical sequence, the preceding classification will be followed in this chapter. The various types will be taken up under their proper subdivisions and any special construction, advantage, etc., will be pointed out. The machines described will be selected as

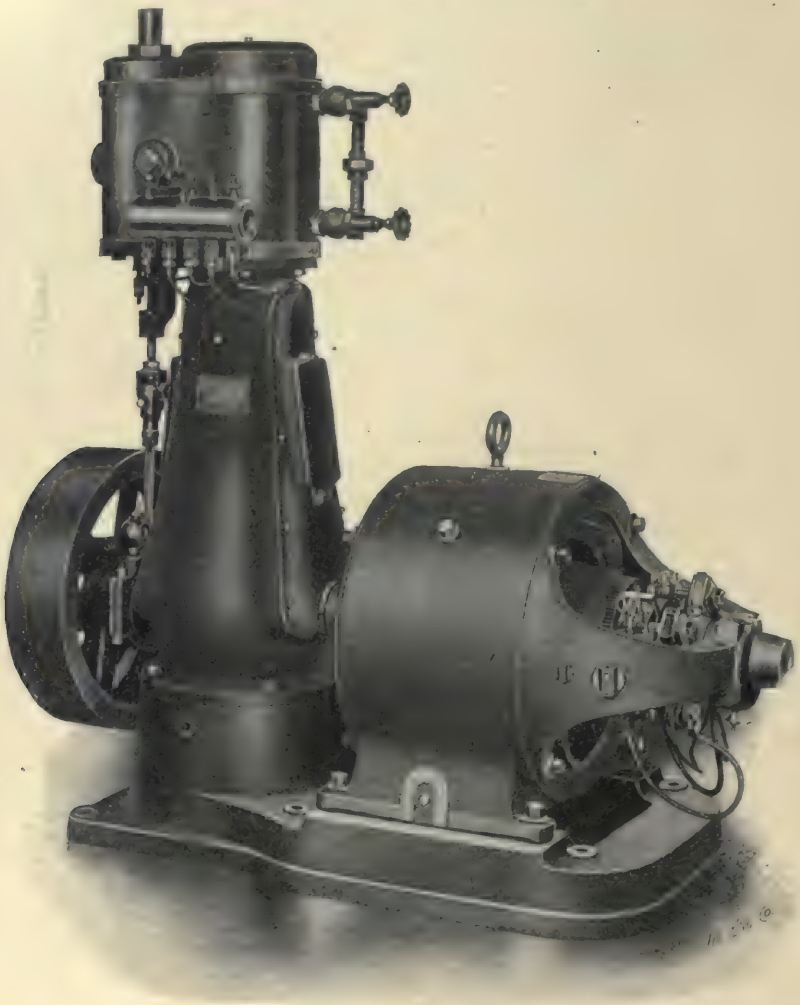

Fig. 3. Racine Automatic Engine and Northern Electric Generator.

illustrating the best standard practice or for some distinctive feature, but it must be remembered that this treatment cannot pretend to do more than introduce the reader to the subject.

GENERATORS

The methods of driving generators in this country to-day are: by direct connection to the prime mover; by means of belting (including rope-driving, which is rather exceptional), and by means of gearing.

Direct-Connected Generators. Direct-connected or direct-driven generators are manufactured in combination with steam engines, gas engines, water wheels, and steam turbines; the generator being in any particular case of the direct- or of the alternating-current type as desired.

A direct steam- or gas-engine driven generator may be arranged in one of three different ways. *First.* It may have its revolving part carried by the engine shaft proper and is usually then denoted as an *engine-type generator.* Such a generator, as shown in Fig. 1, has no shaft and no bearings of its own, both shaft and bearings being provided by the engine maker. *Second.* The engine shaft may be extended out to one side of the engine, which extension then carries the revolving part of the generator, as shown in Fig. 2. There is then provided in this arrangement an extra bearing, usually called an *outboard bearing.* *Third.* Both engine and generator may be complete in themselves and their shafts be directly coupled together by a suitable coupling either rigid or flexible. This arrangement is illustrated in Fig. 3. In all cases a fly wheel is provided, increasing the inertia of the rotating parts and thus increasing the uniformity of rotation.

A direct water-wheel driven generator may be arranged with a vertical or with a horizontal shaft. Those with a vertical shaft are most usually of the alternating-current type, ranging in size from about 100 up to 5,000 kilowatts in capacity, although they are sometimes direct-current generators, as shown in Fig. 4. When the revolving part of the generator is mounted directly upon the vertical shaft of a turbine, some form of thrust or step bearing becomes necessary to support the combined weight of the revolving generator and turbine parts. The pressure on the bearings is de-

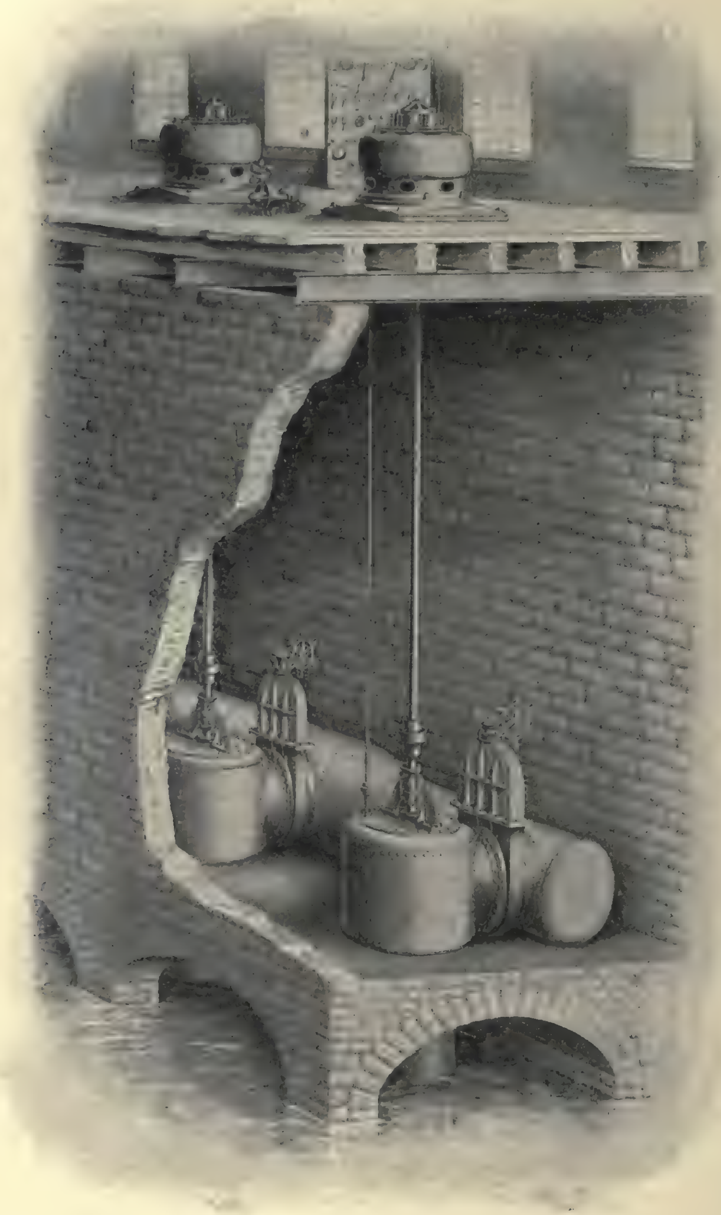

Fig. 4. Generators Connected Direct on Top of Turbine Shaft. Trump Mfg. Co.

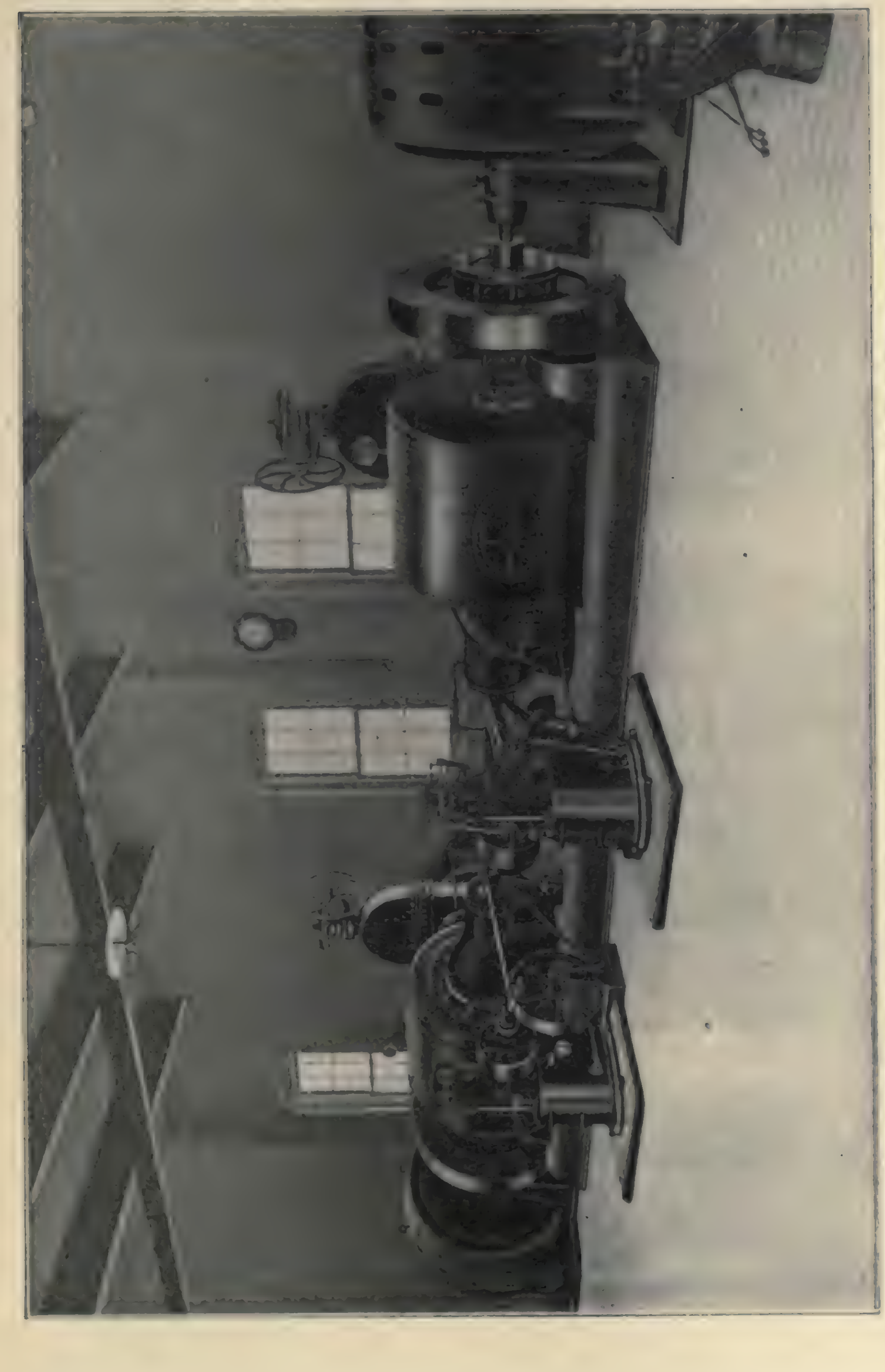

Fig. 5. Interior View of Power Plant of the Dalton Power Company, Dalton, Massachusetts. Two Units of 21-inch "New American" turbines, operating under 152 feet head, direct connected to generator.

creased in some instances by balancing all or a part of the weight, either by the upward pressure of the water in the turbine or by the magnetic pull between the field and the armature of the generator. Fig. 5 shows the arrangement of horizontal shaft turbines directly connected to a direct-current generator, and Fig. 6 shows a direct-current generator driven by a turbine of the impulse type. Direct-current generators direct driven by water wheels are in most cases railway generators.

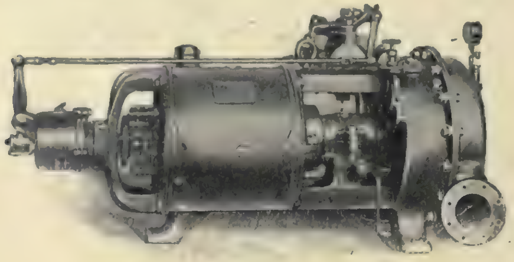

Fig. 6. Generator Driven by Small Water Turbine. Crocker-Wheeler Co.

Direct steam-turbine driven generators are also manufactured with vertical or horizontal shafts. An example of the vertical type is the *Curtis steam turbine unit* manufactured by the General Electric Company and shown in Fig. 7. The generator of this type of unit is, however, as manufactured at present, always a three-phase alternator. Illustrations of *horizontal-shaft steam-turbine units* are given in Figs. 8 and 9.

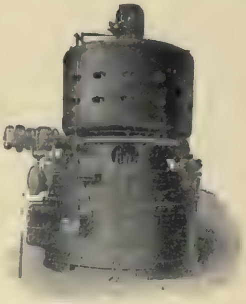

Fig. 7. Curtis Steam Turbine Generator Unit.

Belted Generators. Generators that are not direct connected to their prime movers are most usually driven by belt, or in rather special cases, by some form of rope drive. Belt-driven generators up to 150-K. W. capacity, usually carry a metal, wooden, or paper pulley, that merely overhangs the main bearings. If the generator is larger, or from 150- to 500-K. W. capacity, a third bearing is provided to relieve the bending strain occasioned by the belt pull. The prime movers used in connection with belted generators are generally only steam engines, gas engines, and water wheels. In the smaller sizes in isolated plants, however, are found

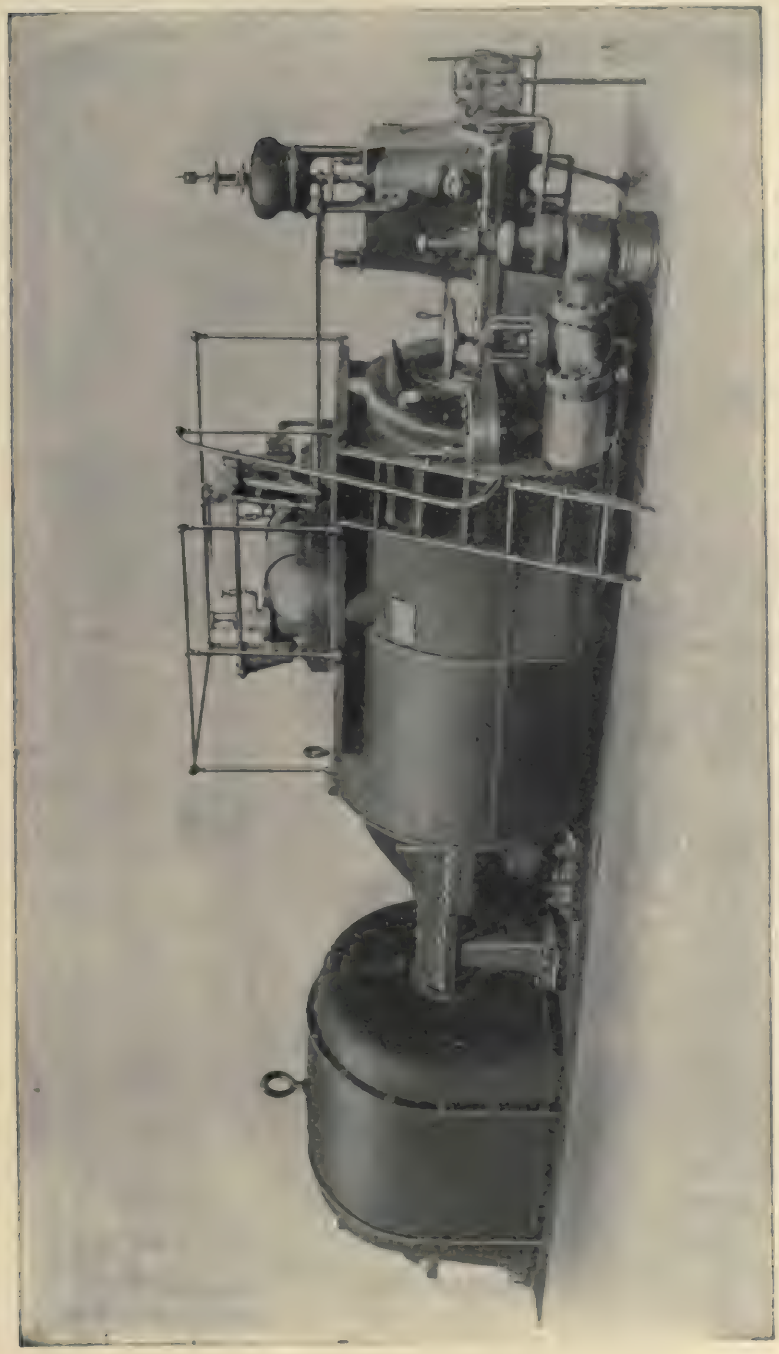

Fig. 8. Westinghouse-Parsons Turbine-Generator Unit of 3,000-Kilowatt Rated Capacity as It Appears when Installed.

various internal combustion engines. The steam turbine, however, is never belted to a generator, since in the smaller powers it rotates at very high speed, rendering the use of belting impracticable.

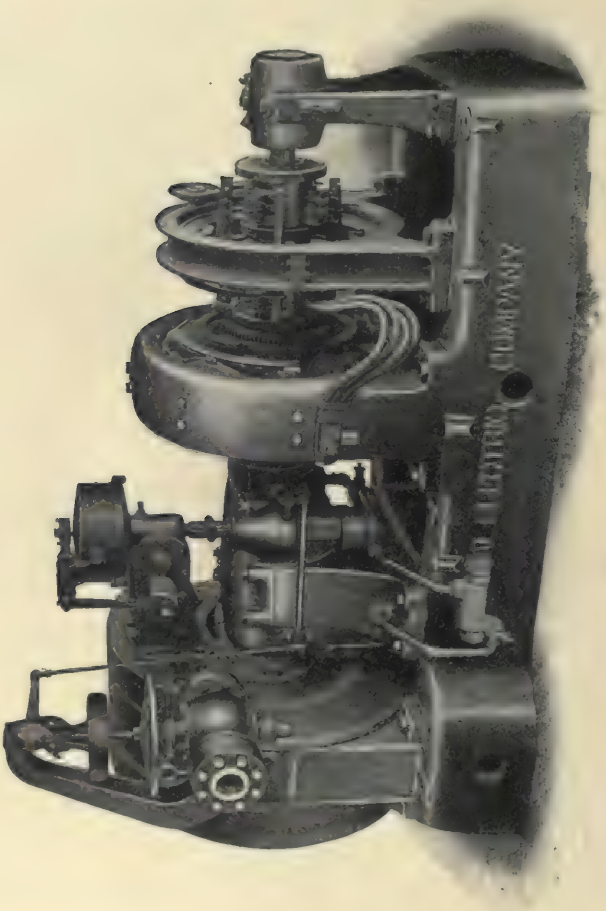

Fig. 9. 100-K. W. Turbine Connected to Direct-Current Generator.

Geared Generators. Gearing is only used for driving generators in the following cases: *First.* Vertical-shaft water wheels and horizontal-shaft generators are often connected in case of low heads by means of bevel gearing, the generator shaft revolving at a higher speed than the turbine. *Second.* In smaller sizes, steam turbines and generators are connected by means of gearing, the generator shaft revolving at a lower speed than the steam-turbine shaft. An example of this method of connection is given in Fig. 10, although this method of driving twin generators is no longer used by the De-Laval Company. *Third.* Direct-current generators used as exciters for large direct-connected alternators are sometimes geared to the shaft of the main prime mover.

Capacities, Speeds, Number of Poles. Direct-current generators are manufactured in standard sizes, varying in capacity from a fraction of a kilowatt to 2,700 kilowatts. Sizes above 200 K. W. are nearly always direct driven, although belted generators are found up to 500 K. W. Below 200 K. W either method is employed, depending upon the special conditions of the case.

The speeds at which direct-current generators are driven, vary from 70 or 75 revolutions per minute in the largest sizes of engine type, up to 2,000 in the belted and 3,000 in the steam-turbine driven types. In general, the greater the kilowatt capacity the lower the speed; although even this general rule does not hold in comparing different lines. Belted generators are very seldom run below 300 to 400 revolutions per minute, while 325 is a rather high speed for a direct-driven generator if we except the generating sets and marine sets run by vertical engines. These latter, in the very smallest sizes, reach a speed of 850 revolutions per minute.

Modern direct-current generators are always multipolar as soon as their capacity is above 5 or even 3 kilowatts, the number of poles increasing with the size of the generator. Belted generators usually have 4, 6, or 8, and occasionally 10 poles. Direct-driven generators, since the speed is fixed by the prime mover, are designed to meet these conditions. Such machines have seldom less than 6 poles and in the larger sizes as many as they have 24 to 36.

Selection of Types. At the present time (1909), the best modern practice employs direct-driven generators whenever possible, and only the smaller units are ever belt driven, since even the best system of belting is unsatisfactory for transmitting large amounts of power. Direct driving necessitates, in general, a larger, heavier, and, therefore, more expensive generator for the same capacity; but the compactness, simplicity, positive action, and general advantages of direct driving are so great that in most cases they warrant the in-

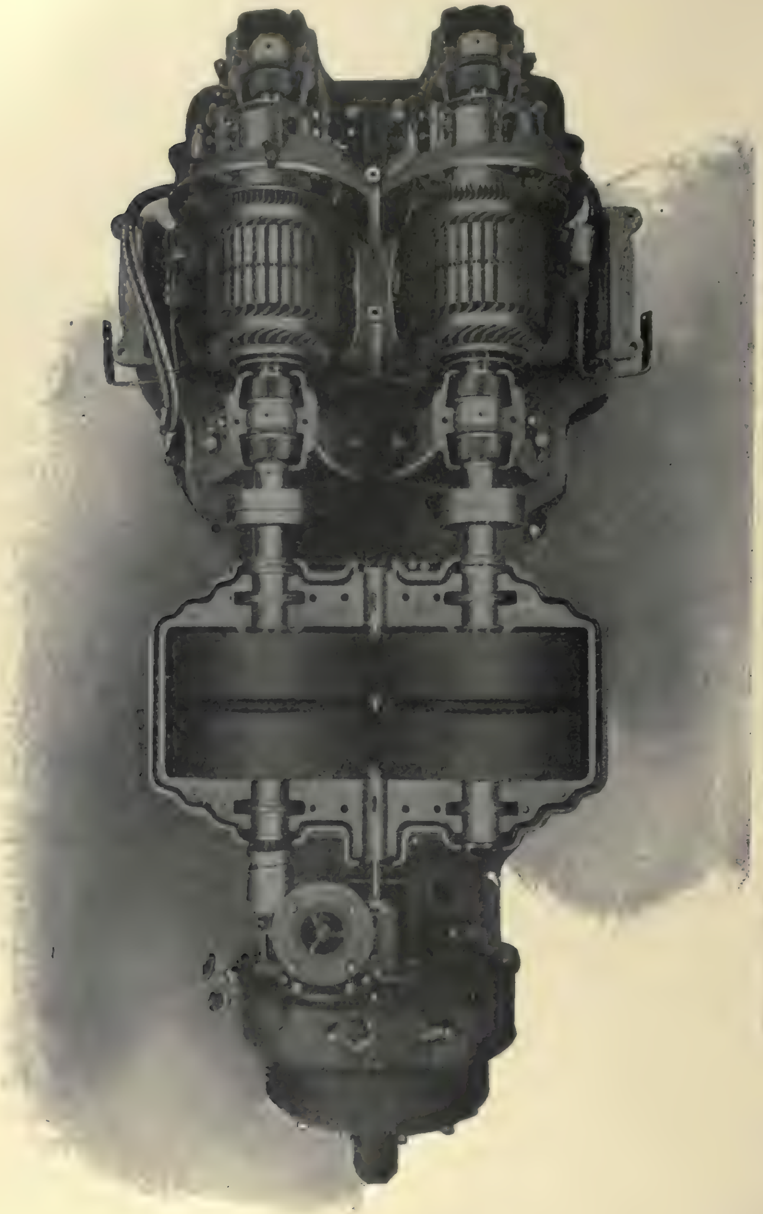

Fig. 10. 110 H. P. Turbine Dynamo—Upper Half of Gear Case and Field Frame Removed.

creased cost. An important advantage possessed by the direct-connected generator is the small floor space required. In some instances this allows a saving in the cost of the building and in the real estate and thus more than counterbalances the increased cost of the generating unit. In belt driving, the distance between the centers of the engine and generator shaft should be at least three times the diameter of the engine pulley to insure satisfactory working of the belt. In some cases, however, the belt-driven generator may be preferable; particularly in the smaller sizes, where only the cost of the units are to be considered, or on account of the ease with which it can be adjusted to engines already in use.

Classification. Direct-current generators, according to their electrical design, may be divided into two main classes: those giving constant current, feeding series circuits; and those maintaining constant voltage, feeding parallel circuits.

Constant-current generators are still found supplying current to series, street, arc-lighting circuits, and in the types used at present deliver approximately from 5 to 10 amperes, their voltage being variable, depending upon that needed by the circuit they are supplying. The manufacture of these series generators has been practically discontinued. New installations of street lighting employ alternating current or else direct current obtained by means of mercury arc rectifiers. The series machines still in use are of the Brush, Thomson-Houston, and Wood types. Of these, the Brush and Thomson-Houston have open-coil armatures and the Wood has a closed-coil armature. As these machines are rapidly becoming obsolete, no further descriptions will be given of them.

Constant-voltage generators may be further subdivided into those giving 5 to 12 volts, those giving about 125 volts, those giving about 250 volts, and those giving 500 to 600 volts. Generators designed to give from 5 to 12 volts are employed for electroplating and electrochemical purposes. Where sufficient number of vats can be connected in series, however, regular standard 125-volt machines are preferably employed. 125-volt generators are used for indoor arc and incandescent lighting, for the running of smaller motors, and in connection with the three-wire system. 250-volt machines are used principally for power purposes, and with auxiliary devices can supply a three-wire system. 500- to 600-volt machines are employed as generators for power and railway circuits. These machines, although denoted as constant voltage, are generally designed so that by means of their compound winding they overcompound, usually 5 or 10 per cent; that is, at full load their voltage is 5 or 10 per cent higher than at no load.

The uses to which direct-current generators are put, we find, therefore, to be in connection with series arc lighting, constant-potential lighting, power, railway, and electrochemical purposes.

Descriptions of Types. *Allis-Chalmers Company.* This company has absorbed the Bullock Electric Mfg. Co. and continues to use the old name on some of their electrical apparatus. Their engine-type generators are designed for general lighting and power service, and are built for standard full-load pressures of 120, 240, and 525 volts. They are compound wound, giving variation in voltage from no load to full load; the no-load voltages being 115, 230, and 500 respectively. These machines are made in a great variety of capacities and speeds, ranging from 12 to 1,000 K. W. and run at speeds from 70 to 470 revolutions per minute. Fig. 11 shows an 800-K. W. generator of this type, direct connected to a cross-compound Corliss engine. The cast-iron field frame is of circular form and has an elliptical cross-section. The two parts of the yoke, divided hori-

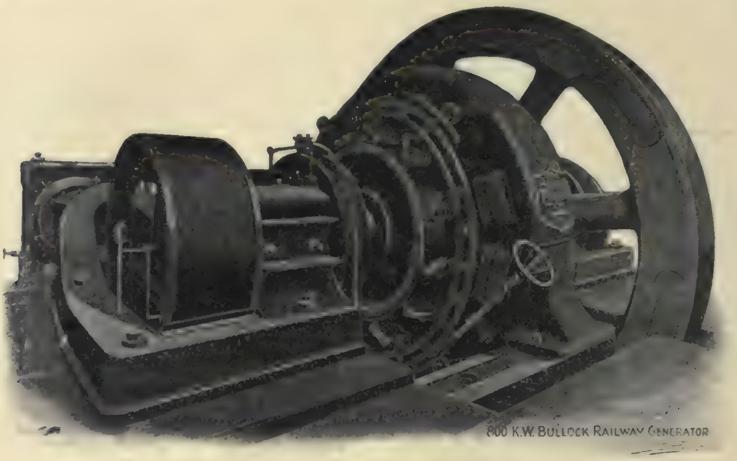

Fig. 11. 800-K. W. Bullock Generator.

zontally, are bolted together by cap screws having their heads set in pockets covered by suitable plates. The pole pieces are generally made of steel punchings riveted together. The poles are bolted to the inside surface of the yoke. By holding the poles in place with screws, accurate spacing can be obtained, and by removal of one or more poles, field coils can be changed, or minor armature repairs made without dismantling the whole machine. Fig. 12 shows a portion of the field of a 500-K. W. generator, with the shunt and series windings in place. The armature core is dovetailed to a massive cast-iron spider, shown in Fig. 13. The core proper is built up of thin sheet steel laminations of high magnetic permeability and contains ample radial ventilating ducts The armature coils are made of rolled copper strips, so shaped as to be interchangeable. Each conductor is insulated with linen tape, then the conductors that are to be placed in the same slot are grouped together and the slot insulation wrapped around them as a whole. This group of conductors is then placed in a steam-heated screw press and there pressed into shape to fit the armature slot, the high temperature removing all the moisture. The coils are held in position in the armature slots by hardwood wedges fitted into grooves at the top of the slots. No band wires are used under the poles, but a steel

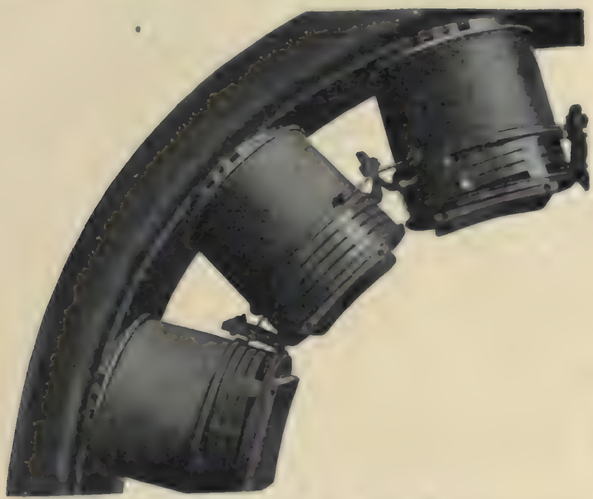

Fig. 12. Portion of Field 500-K. W. Bullock Generator.

wire band at each end of the armature serves to keep the ends of the coils in place. Fig. 14 shows an armature core and commutator, with temporary shaft, before the windings are put on. This type of armature, with conductors placed in deep slots, and not wound on the armature surface, is known as an *ironclad armature,* and is the standard form adopted by all manufacturers to-day. Fig. 15 shows a smaller generator of this type. This view shows the brush-holder mechanism, carried on the large ring supported from the yoke by three small wheels. The position of the brushes is adjusted by turning the hand wheel.

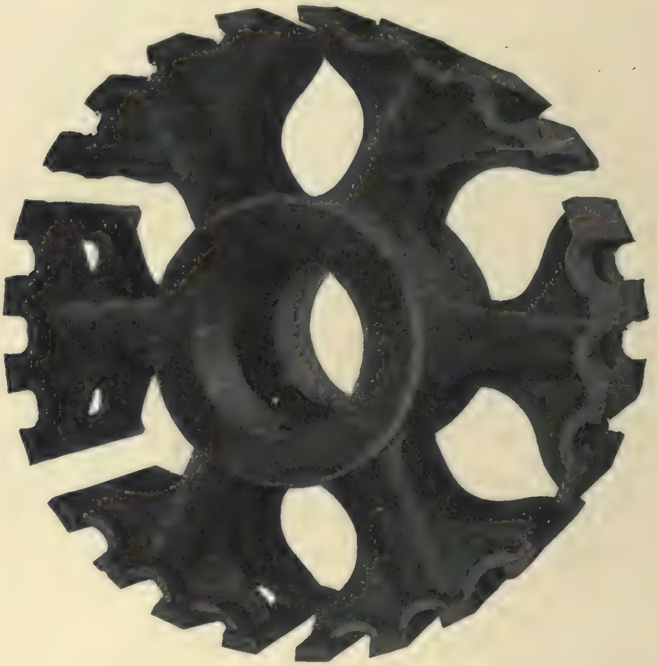

Fig. 13. Spider for Bullock Armature.

The Bullock belted generators manufactured by this company are intended to fulfill every requirement but the smallest capacities. The materials, methods, and processes employed in their manufacture are the same as for their engine types. Fig. 16 illustrates this line of machines, the large sizes having a third or *outboard* bearing, as shown in Fig. 17. For the smaller belted sizes this company uses its type *K* machines. These latter are identical with their motors, merely having a series field winding added, and will be described in detail later.

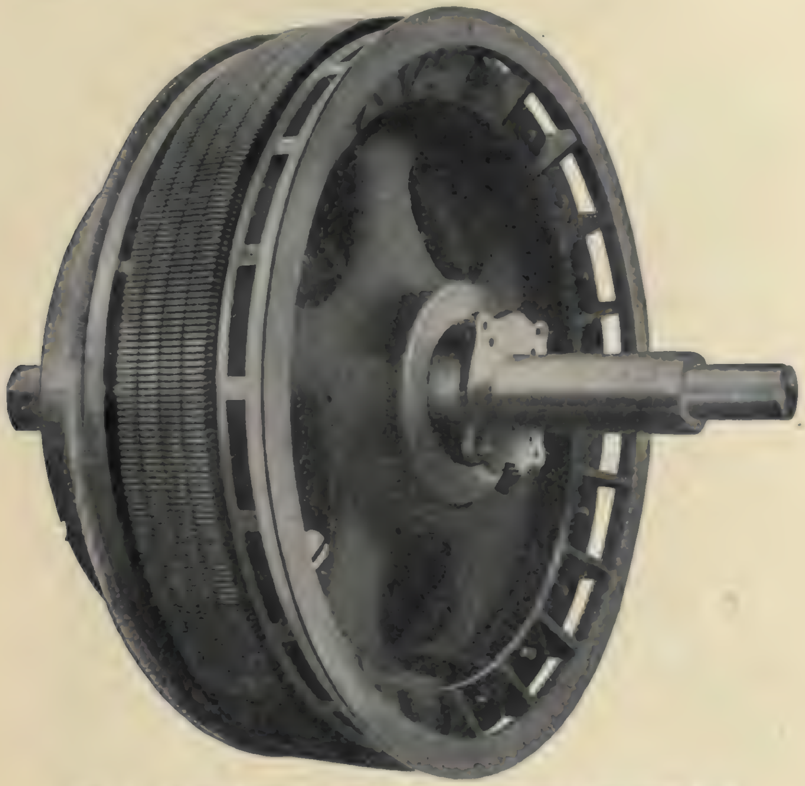

Fig. 14. Bullock Armature Core and Commutator with Temporary Shaft.

Garwood Electric Company. This company manufactures the C & C generators and motors. An illustration of their 6-pole engine-type generator is given in Fig. 18. These machines are made in standard sizes from 25 to 200 K. W., running at speeds from 325 to 200 R. P. M. The smallest size has 4 poles, the largest three have 8 poles, and the others, 6 poles. The field magnet yoke of soft steel is cast in two semi-circular halves and bolted together. The pole pieces and their shoes are solid steel castings bolted to field yoke or ring. The armature spider is of substantial construction with its hub extended into a long sleeve that also carries the commutator. The armature core, built up of thin, soft-steel stampings, is keyed and bolted to the spider. The core is slotted to receive the armature windings and is well ventilated by air ducts running parallel with and at right angles to the shaft. The commutator is made of rolled copper bars and is of ample size, giving good wearing qualities. Fig. 19 shows a C & C belt-driven generator with overhanging pulley.

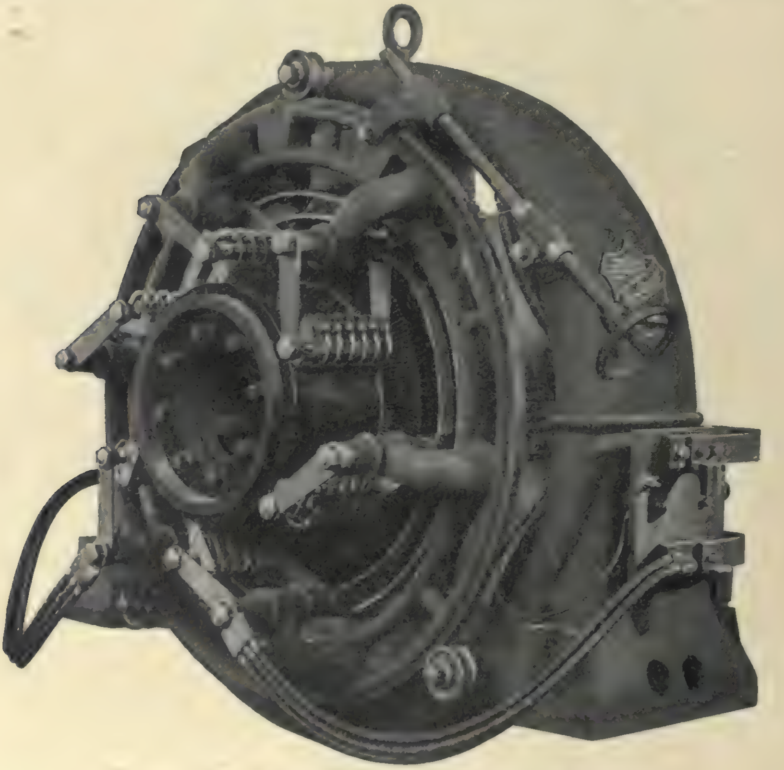

Fig. 15 Small Type *I* Bullock Generator (without shaft).

This line of machines is made in standard sizes from 25 to 300 K. W., running at speeds from 650 to 200 R. P. M. Three-bearing generators are furnished in capacities from 125 to 300 K. W., while the largest two-bearing machine is 225 K. W. In their general construction this line resembles the engine-type machines of this company. Another line of belt-driven machines is illustrated in Fig. 20. These machines, designated type *SL*, are all of the four-pole type; capacities, one and a quarter to 35 K. W.; speeds 1,780 to 740. The magnet frame or yoke, the four poles, and the supporting feet are cast of the best soft steel in one piece. The protecting rings, which protect the

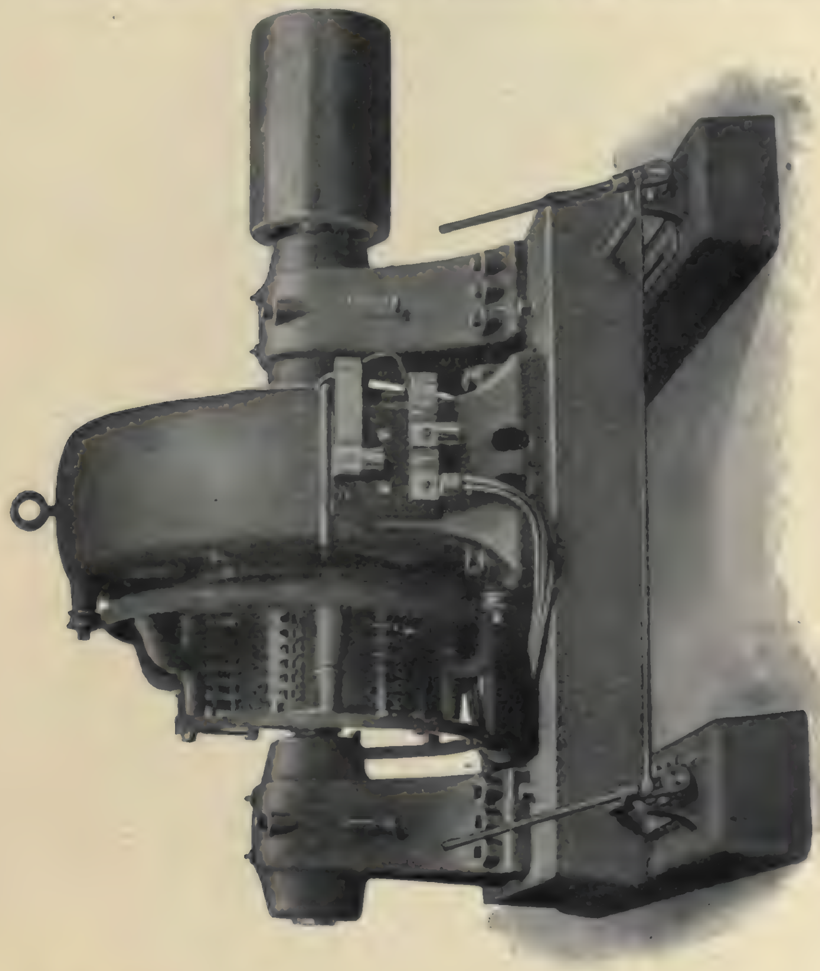

Fig. 16. Bullock Belted Generator.

field coils and support the brush rigging, are cast integrally with the bearing brackets. This piece is of cast iron and is attached to the magnet frame by dowel pins and cap screws. The field coils are carefully wound on easily removable sheet-iron bobbins. All C & C machines employ special brush holders of the reaction type, carry-

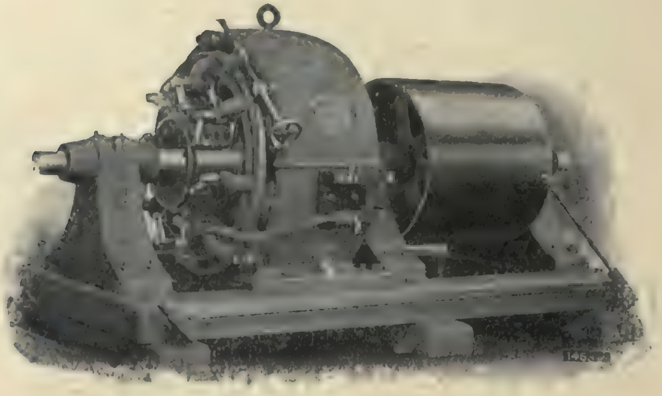

Fig. 17. Bullock Belt-Driven Generator.

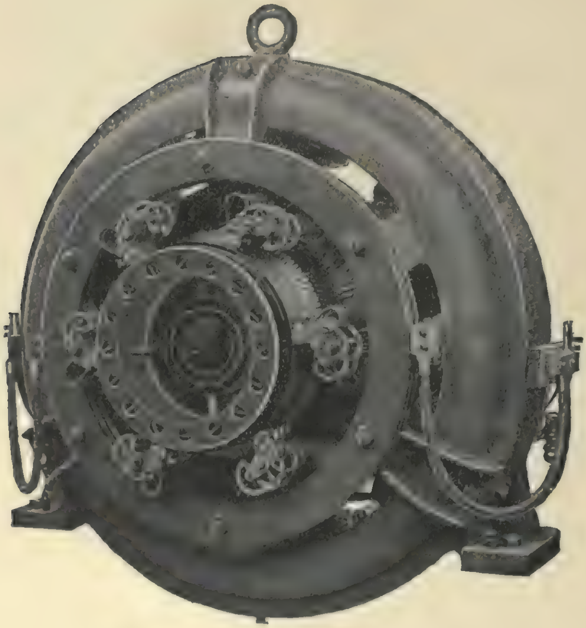

Fig. 18. C & C Engine-Type Generator.

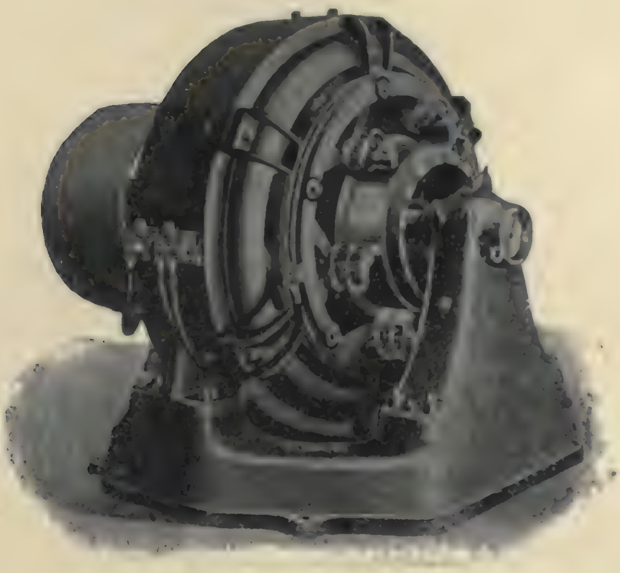

Fig. 19. C & C Belt-Driven Generator.

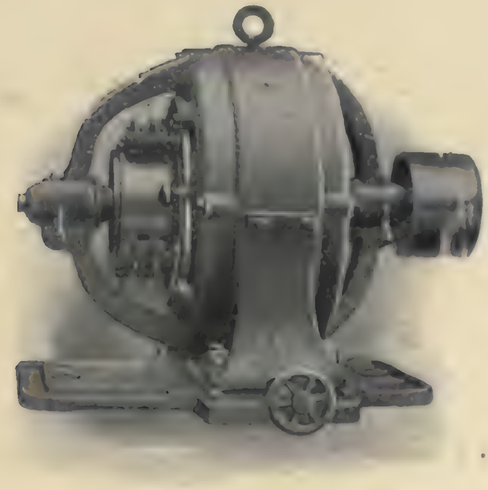

Fig. 20. C & C Type S L Belted Generator.

ing carbon brushes inclined at a slight angle from the radial line and also use bearings of the self-oiling, self-aligning type, in which brass rings in the oil wells carry the oil to the shaft. The generating sets put upon the market by this company vary in capacities from one and a half to 100 K. W. and are selected sizes of the preceding lines directly coupled to vertical high-speed engines of various other manufacturers.

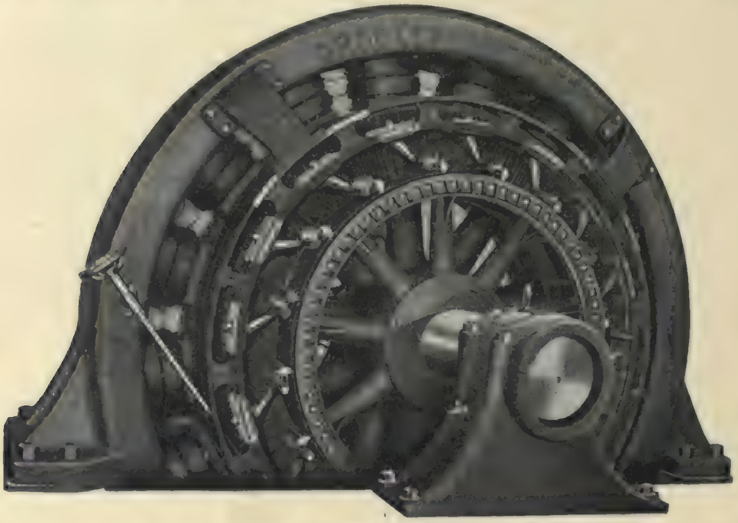

Fig. 21. Crocker-Wheeler Engine-Type Generator.

Crocker-Wheeler Company. The line of engine type generators built by this company is in sizes from 200 to 1,200 K. W., running at various speeds from 225 to 85 R. P. M., and having from 8 to 24 poles. For direct connection they also build a number of 4- and 6-pole machines in sizes from 25 to 150 K. W. whose speeds range from 325 to 200. One of the larger sizes is shown in Fig. 21. In these generators the magnet frame is of cast iron, stiffened by internally projecting flanges. The frame is split horizontally, the two halves being accurately fitted and bolted together. The lower half of the frame is provided with feet that are bolted down to the supporting base and are supplied with leveling screws for accurately adjusting the position of the magnet frame. The poles are of steel, cast welded into the frame, thus securing a perfect magnetic joint. This is accomplished by constructing the poles first and placing them in position in the mould in which the magnet frame is to be cast. In casting the magnet frame, the molten metal flows around the ends of the magnet poles so that, on cooling, one solid mass results. If the cast-welded joint is perfectly made, it certainly results in a better magnetic circuit than by the method of bolting. Each pole is fitted with a cast-iron removable shoe that produces the desired flux distribution and also holds the field coils in position. The air-gap or clearance between the armature and the pole pieces is relatively large. This is a good feature, as it tends to reduce the bad effects occasioned by the armature being slightly out of center. The field coils on each pole are divided into sections separated from each other and from the pole by spacers, so as to provide increased ventilation. The armature spider, besides supporting the sheet steel, toothed laminations of the core, also carries the commutator spider. The armature conductors consist of flat or round copper wire, without joints of any kind. The cast-iron rocker ring, carrying the brush rigging, is rigidly supported from the magnet frame. All C-W machines employ parallel movement brush holders, illustrated in Fig. 22. This company also manufactures a line of 550-volt engine type, railway generators, embodying the preceding features, in sizes from 125 to 1,000 K. W., with 8 to 16 poles and running at 275 to 80 R. P. M. Their belted

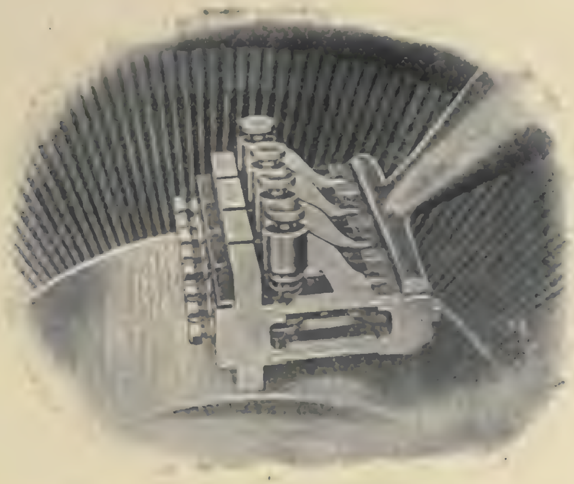

Fig. 22. C-W Parallel Movement Brush Holder.

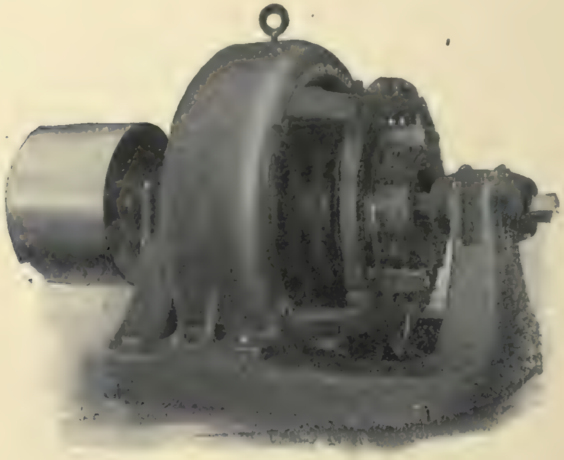

Fig. 23. Crocker-Wheeler Form *D* Generator.

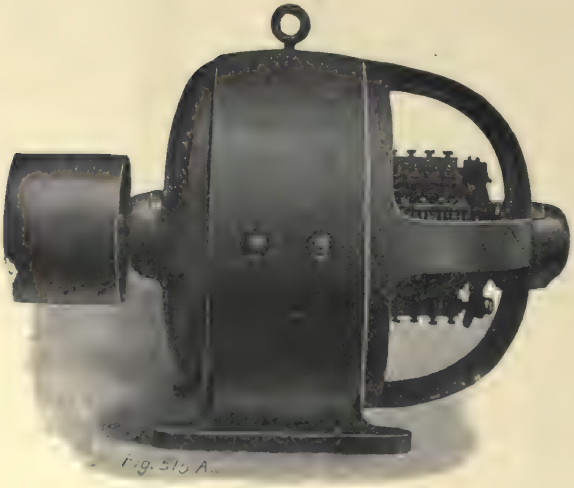

Fig. 24. Crocker-Wheeler Form *I* Generator.

generators are built in two separate lines, their form *D* and their form *I* machines. Form *D* generators are built on the same general lines as their engine-type generators but for higher speeds. They range in output from 45 to 225 K. W. and in speed from 420 to 900 R. P. M. Fig. 23 illustrates this line of machines. The base is hollow and has the bearing pedestals cast solid with it. The bearings have rigid journal boxes, giving stronger support to the shaft than self-aligning boxes, the latter being considered undesirable when the pedestals are rigid on the base. Their form *I* machines, shown in Fig. 24, give them the smaller sizes, from 4½ to 40 K. W., ranging in speed from 1,550 to 825 R. P. M. These machines are multipolar and have a round frame of which the feet form a part. The bearings are supported by four-arm castings attached to the yoke. The armature coils are of heavily insulated wire and form wound. After being taped and dipped in an insulating varnish they are baked. These machines, when direct connected to vertical high-speed engines of other manufacturers, give rise to generating sets from 1¼ to 19 K. W., running from 850 to 380 R. P. M.

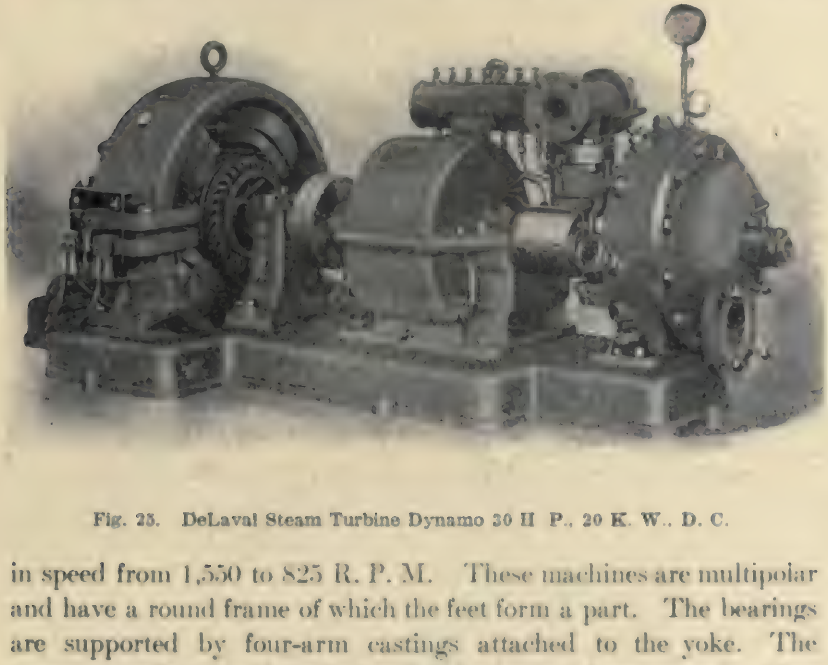

Fig. 25. DeLaval Steam Turbine Dynamo 30 H. P., 20 K. W., D. C.

DeLaval Steam Turbine Company. This company put a line of units on the market in which the generators were geared to steam turbines in capacities from 4.6 to 200 K. W.; the generator speeds were from 3,000 to 9,000 and the turbine speeds from 3,000 to 10,000 R. P. M. Fig. 25 shows a 20-K. W. unit of the older type. All units from 50 to 200 K. W. inclusive, until recently, consisted of really two generators mounted side by side but with a combined field frame, and their armatures coupled to the reducing shafts, as shown in Fig. 10. This style has been abandoned, the newer type being illustrated in Fig. 26. The field frame is cast steel and in the larger units resembles two intersecting circles in shape. The pole pieces are

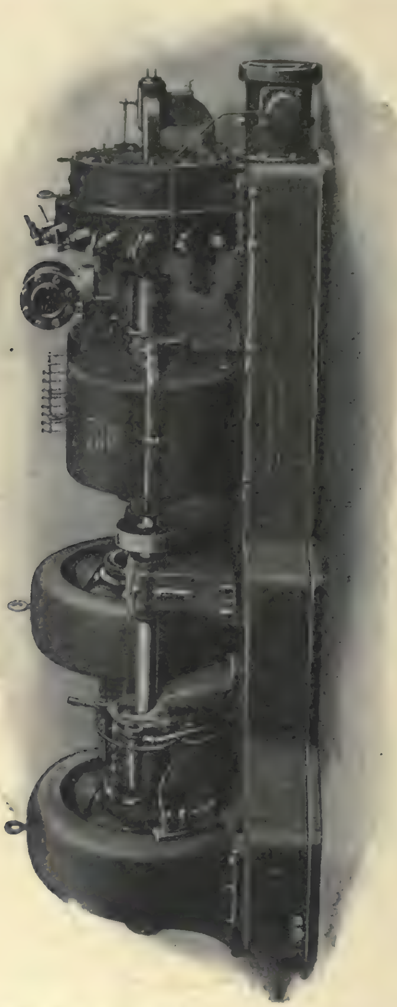

Fig. 26. Turbine Dynamo, 300 H. P., 200 K. W.

built up of thin sheet-steel laminations, each one being held in place by two bolts passing through the field frame. The series and shunt field coils are machine wound, are independently insulated, and are mounted on the pole pieces without bobbins. The armatures are of the ironclad, bar wound, ventilated type. The armature conductors are wound with linen tape, dipped in varnish and baked. As many as are placed in one slot are then taped together. The coil is now dipped in insulating varnish and again baked. The slots contain insulating troughs made of a combination of varnished cloth and insulating paper. The commutators are of extremely heavy construction mounted directly on the armature shaft. The brush-holder yoke consists of a cast-iron ring supported by brackets projecting from the magnet frame.

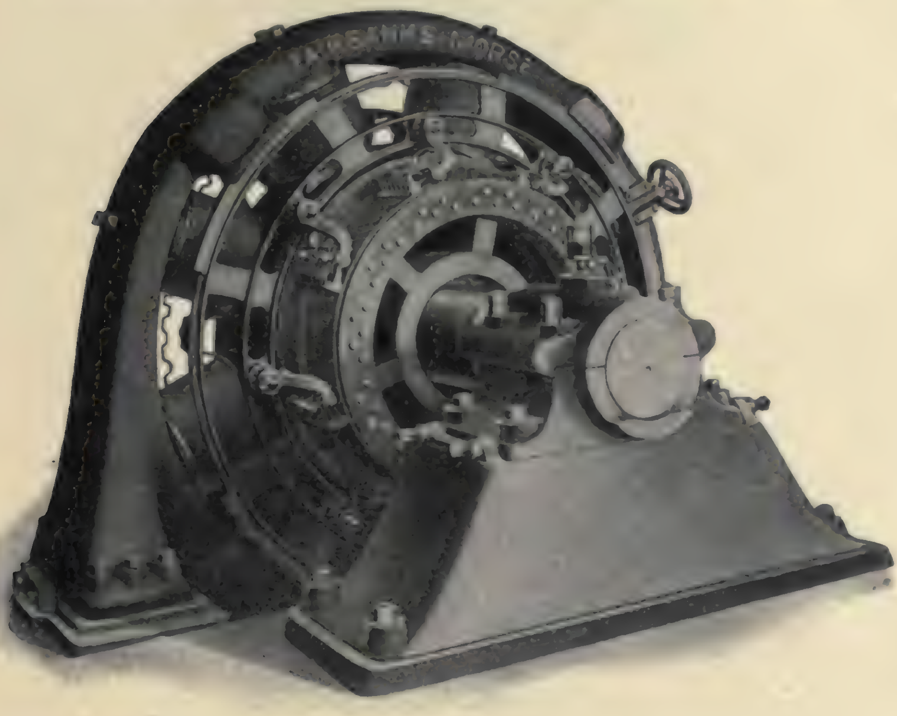

Fig. 27. Fairbanks-Morse Engine-Type Generator.

Fairbanks, Morse & Co. The engine-type generators gotten out by this company are illustrated in Fig. 27, showing a 200-K. W.,

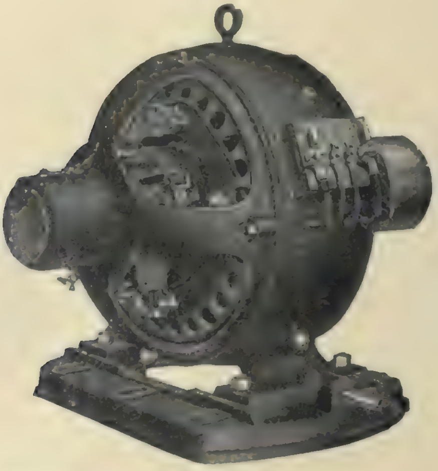

Fig. 28. Fairbanks-Morse Belted Generator.

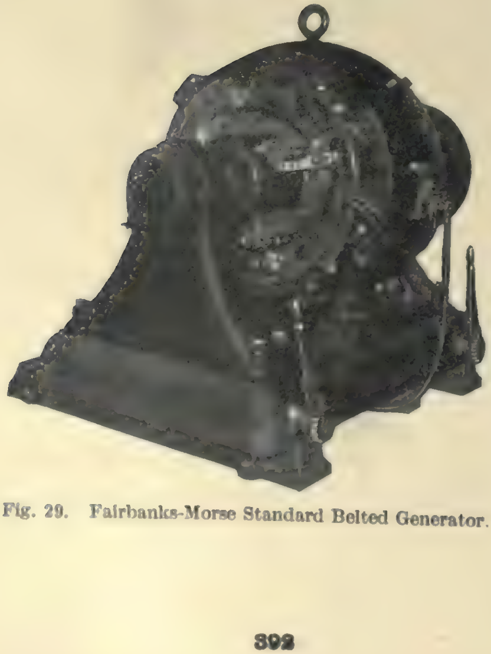

Fig. 29. Fairbanks-Morse Standard Belted Generator.

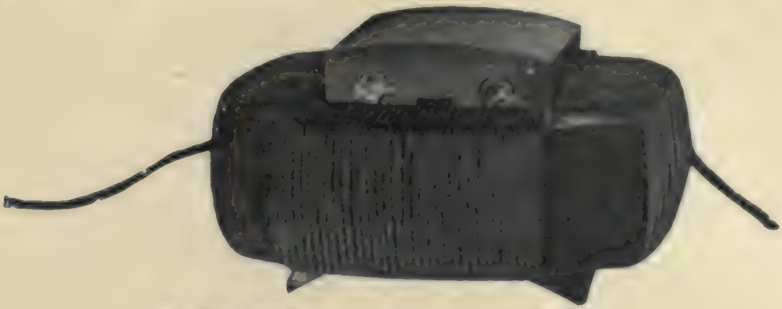

Fig. 30. Field Poles and Coils—Fairbanks-Morse.

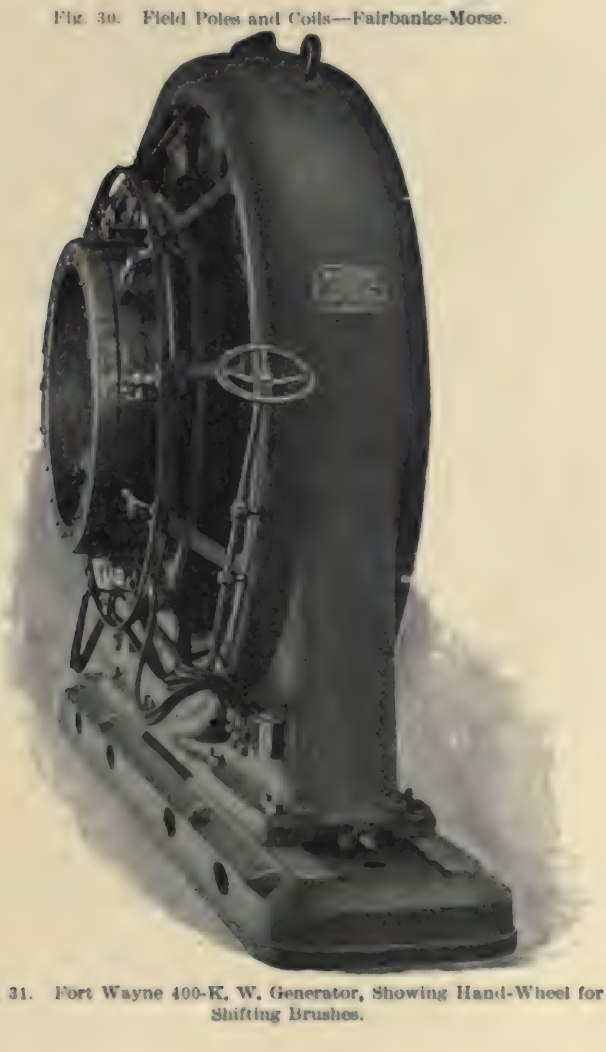

Fig. 31. Fort Wayne 400-K. W. Generator, Showing Hand-Wheel for Shifting Brushes.

250-volt machine. They are manufactured in sizes from 50 to 300 K. W., with speeds from 275 to 100 R. P. M. The frame or magnet yoke is made of special dynamo iron of very high permeability. The pole cores are of extra quality re-hammered wrought iron, circular in cross-section and bolted to the frame. The pole shoes are of laminated sheet steel, so shaped as to give the correct flux distribution and avoid eddy currents. The field coils are wound on metallic spools, the series and shunt coils being in separate compartments. The armatures are iron-clad, bar wound, with one-piece coils and well ventilated. This company also manufactures several lines of moderate- and slow-speed belted generators. Their moderate-speed machines range from 2 to 125 K. W., running at 1,850 to 675 R. P. M. These same machines when run at lower revolutions per minute and suitably changing the windings, become their slow-speed generators rated from 1½ to 100 K. W., running at 1,600 to 550 R. P. M. The smaller sizes are illustrated in Fig. 28, while the larger take the form shown in Fig. 29. In these lines the frame is a semi-steel casting. The poles are built up of steel laminations pressed solidly together between steel side pieces, or in the smaller sizes cast solid with the frame. Pole horns support the field coils and give the proper flux distribution in the air-gap. The shunt field coils are wound upon cast-iron forms and thoroughly

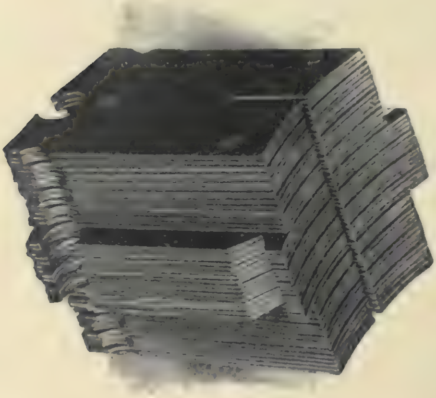

Fig. 32. Fort Wayne Laminated Pole Piece, Before Being Cast-Welded Into the Frame.

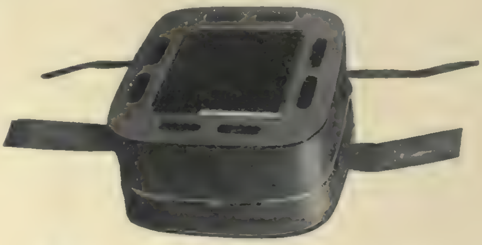

Fig. 33. Fort Wayne Ventilated Field Coil.

insulated. The series coils are made of strip copper, insulated with mica and protected with a cord winding on the outside. This construction is shown in Fig. 30. In the smaller machines the armature coils are form wound.

Fort Wayne Electric Works. The engine-driven generators of this company are built in sizes from 20 to 800 K. W., running at 325 to 80 R. P. M. and having from 6 to 16 poles. Fig. 31 is a view of a 10-pole, 400-K. W., 250-volt generator and clearly shows the method of shifting the brush yoke. In the smaller sizes the frames are split horizontally, while large machines are split vertically and can be separated on the base at right angles to the shaft. The pole pieces are made up of sheet iron punchings, riveted together and slotted to about one-half their length, as shown in Fig. 32. After being cast-welded into the frame, they are machined and in the larger sizes fitted with pole shoes. The field coils are wound on insulated metal

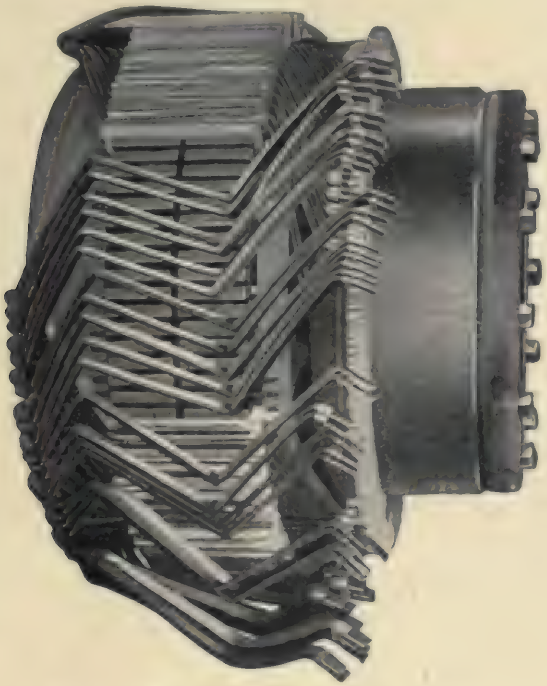

Fig. 34. Fort Wayne Armature Partly Wound.

forms, as shown in Fig. 33, providing good ventilation. The armature is of the usual ironclad, one-piece coil, well-ventilated type. A partly wound armature is shown in Fig. 34. Their belt-driven types are manufactured in sizes from ¾ to 400 K. W. They embody the same characteristics as the direct-connected type, but the base, field frame, pulley end pedestal, and part of the commutator end pedestal are all cast in one piece, with the laminated pole pieces cast welded in the yoke. One of their larger size, 3-bearing belted generators, is shown in Fig. 35.

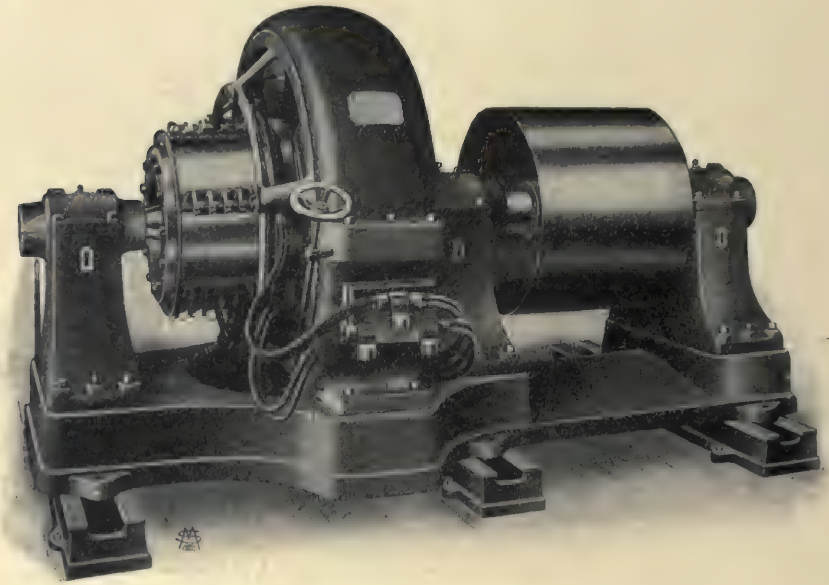

Fig. 35. Fort Wayne Generator, 3 Bearing, 6 Poles, 200 K. W., 550 R.P.M., 550 Volts.

General Electric Company. Fig. 36 shows a direct-connected railway generator built by this company. These machines range in size from 100 to 2,700 K. W., having from 6 to 36 poles, and running at 275 to 75 R. P. M. They are compound wound, generally furnishing 525 volts at no load and 575 at full load. Their line of direct-driven lighting and power generators is of similar design, from 25 to 200 K. W., 6 and 8 pole, running at 305 to 150 R. P. M., and giving 125 or 250 volts. Sizes giving 275 volts are from 300 to 1,600 K. W., with 10 to 24 poles, running at 150 to 100 R. P. M. In all these machines the external circular yoke of the field is made of cast iron of oval cross-section, except in very large sizes, where it is cast with a box-like construction to give greater stiffness. The two halves are fastened by bolts entirely hidden. The poles are solid steel castings, accurately fitted and bolted to the yoke. They are also keyed in such a way that they may be slipped out laterally. Pole shoes, laminated in machines above 200 K. W., are designed to give a graduated flux density in the air gap and also serve to keep the field coils in place. The field coils are rectangular in shape, as shown in Fig. 37. The end flanges of the spools are ventilated, with ducts formed in the coils. In the larger machines, the series and shunt coils are wound on separate parts of the bobbin, while in the smaller sizes

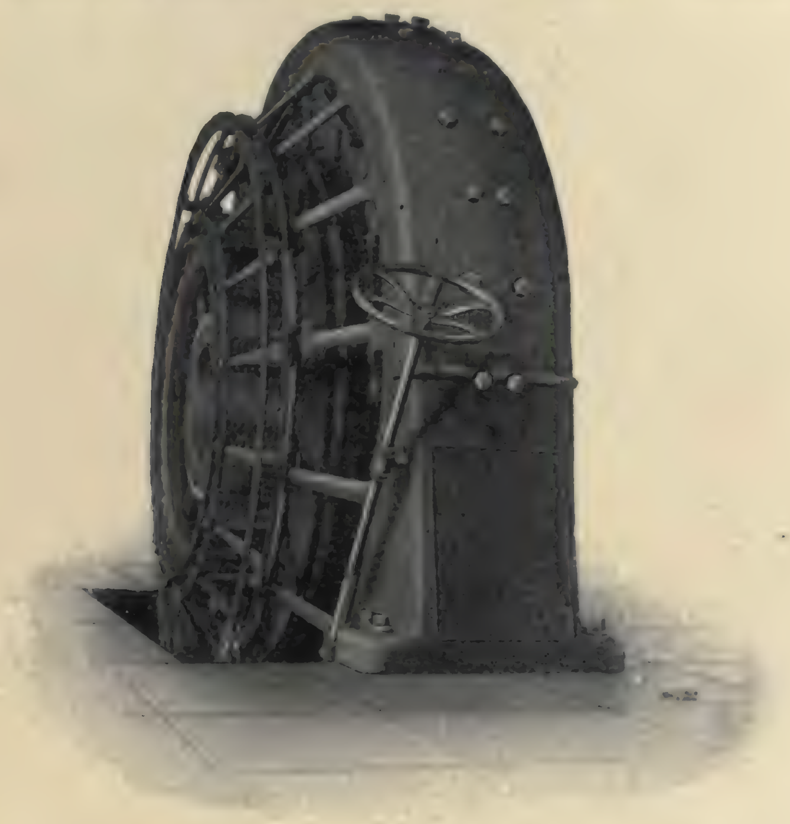

Fig. 36. General Electric Railway Generator.

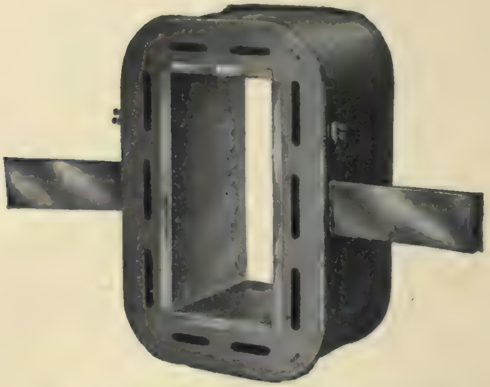

Fig. 37. General Electric Ventilated Field Coil.

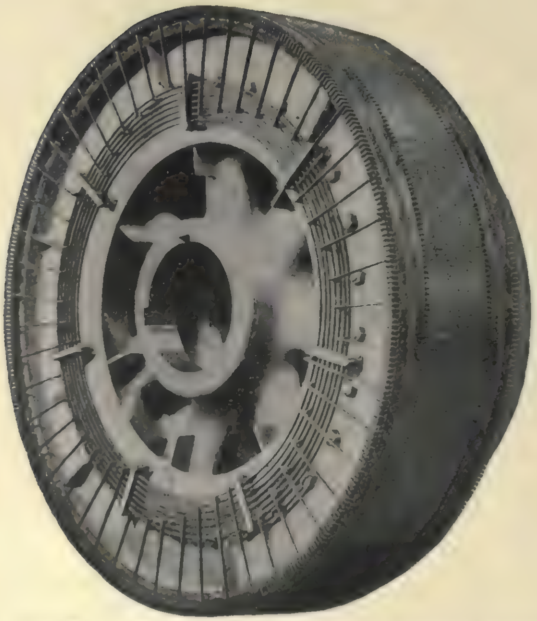

Fig. 38. Rear View of General Electric Armature—Showing Equalizer Rings.

the shunt winding is over the series. The toothed armature core and windings are built up upon the rim of a strong central spider, shown in Fig. 38. At suitable intervals between laminations, space blocks, illustrated in Fig. 39, are inserted. These are made of steel strips set on edge and interlocked with the laminations, thus forming ventilating ducts or air passages. The arms of the spider have cast upon them wings or fan blades. These serve as a powerful centrifugal fan to keep a constant blast of air passing between the laminations and windings and around the poles. The armature coils are of the form-wound copper-strip type, held in the slots by wooden wedges. Equalizing rings are provided on generators having multiple-wound armatures. These rings, mounted on the end flange on the back of the armature, shown in Fig. 38, are used to connect the armature windings between points of equal potential so that any unbalancing that may occur will be equalized by the alternating currents that will flow through these rings between the sections. These currents, due to their armature reaction, equalize the pole strengths, thus causing an equal division of the direct current in the several paths and very much improving commutation. Commutators and brush holders are of generous design, allowing large radiating and contact surfaces. In their railway generators, all sizes above 1,000 and below 400 K. W. are equipped with commutating poles. These compensate armature reaction at all loads and secure excellent commutation. (See Electro-Dynamic Company, Page 66.) Their 250-volt generators become three-wire generators by adding two collector rings, mounted at the commutator end and connected to

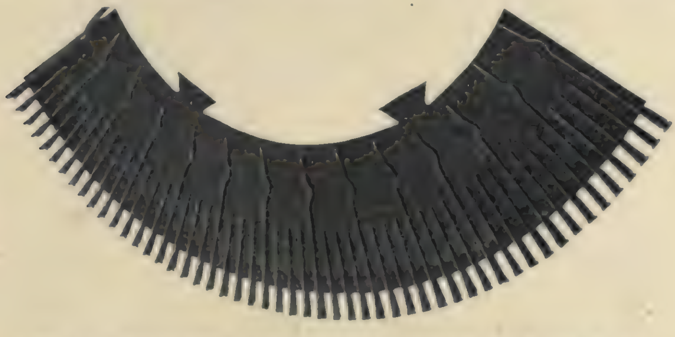

Fig. 39. General Electric Armature Lamination and Space Blocks.

the proper points in the armature winding. Machines of this type up to 200 K. W. are illustrated by Fig. 40. The brush rigging for the collector rings is supported from the pillow block and makes connection by copper brushes to a compensator. These compensators are similar in construction to transformers and consist of two or more insulated coils wound on a laminated iron core. They carry an alternating current and serve to maintain a neutral potential at their middle point to which can be connected the middle or neutral wire of a three-wire system. This company manufactures a line of small direct-current generating sets, both generator and engine complete, in sizes from 2½ to 75 K. W., running at speeds from 700 to 280 R. P. M. Fig. 41 illustrates a 50-K. W. set of this type. Designed to meet the severe conditions of marine work which demands light, very compact, and extremely durable sets of close regulation, they

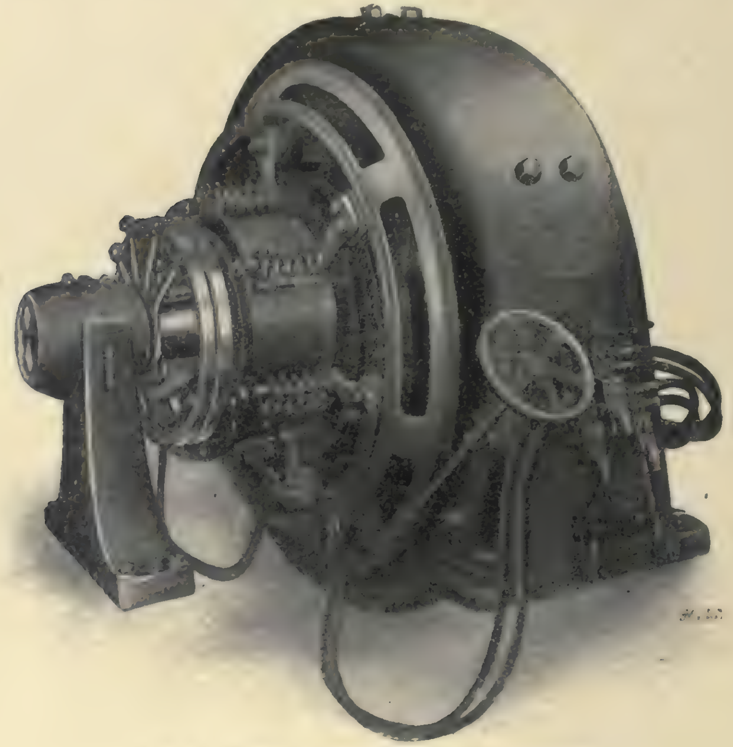

Fig. 40. General Electric Three-Wire Generator.

are, in addition, employed for power and lighting in isolated plants and as exciters in central stations.

The direct-current Curtis steam turbine sets brought out by this company are arranged with horizontal shaft, as illustrated in Fig. 9. They are built in sizes from 20 to 300 K. W., at 125 and 250 volts. The generators are of the most recent and improved types. By the use of commutating poles, sparking under all conditions of load is eliminated. Special commutator constructions, on account of the high speeds and massive brush rigging, are also employed. The generator and steam turbine are mounted on a common base, with a single piece shaft and two bearings, or with a two-piece shaft and flexible coupling between the generator and the turbine, in which case four bearings are required. This company also builds several lines of belted machines. These include railway generators from

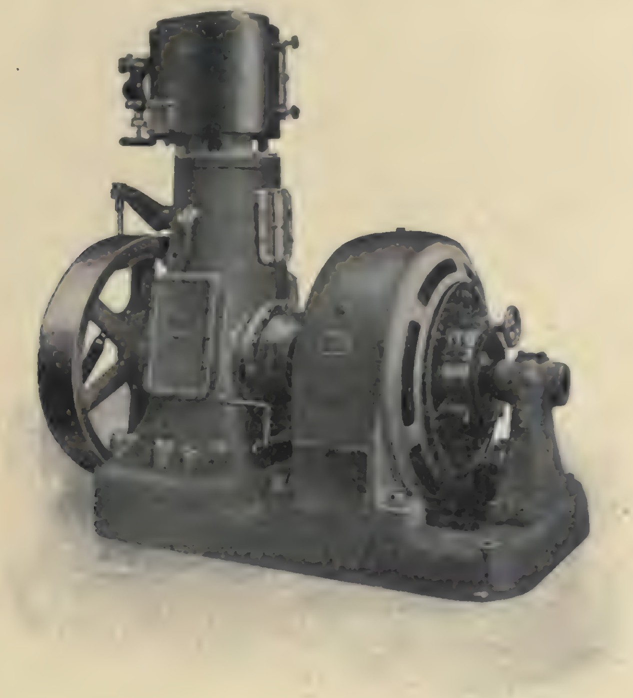

Fig. 41. General Electric 50-K. W. Generating Set with Forced Lubrication.

100 to 300 K. W., 6 and 8 poles, running at 600 to 400 R. P. M.; several lines of lighting and power generators ranging from 1½ K. W., 2 pole, at 1,350 R. P. M., to 200 K. W., 8 pole, at 425 R. P. M. These lines employ similar methods of construction to the respective direct-connected types of the same company. Fig. 42 illustrates their medium-size belted machine while Fig. 43 illustrates this company's double commutator, low voltage generator used for electrochemical work. This machine is capable of delivering 2,000 amperes at 6 volts, or by connecting the two commutators in series, 1,000 amperes at 12 volts.

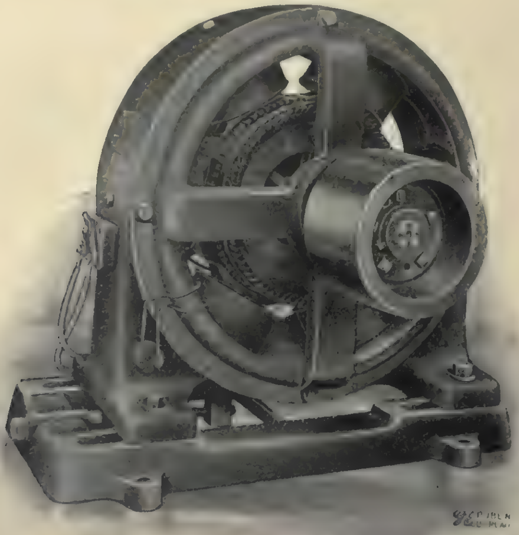

Fig. 42. General Electric 16-K. W. CL-B Generator on Cast-Iron Sub-Base.

Holtzer-Cabot Electric Company. Fig. 44 shows the belted generators built by this company. The line of these machines includes sizes from 1 to 80 K. W., at speeds from 2,250 to 500 R. P. M. The field ring is a one-piece casting with cylindrical pole pieces of wrought iron cast welded into it. The field coils are form wound with mica reinforced insulation. The armature is ironclad with wave windings of round ribbon or bar copper depending upon the size of the machine. The armature coils are held in the slots by maple strips

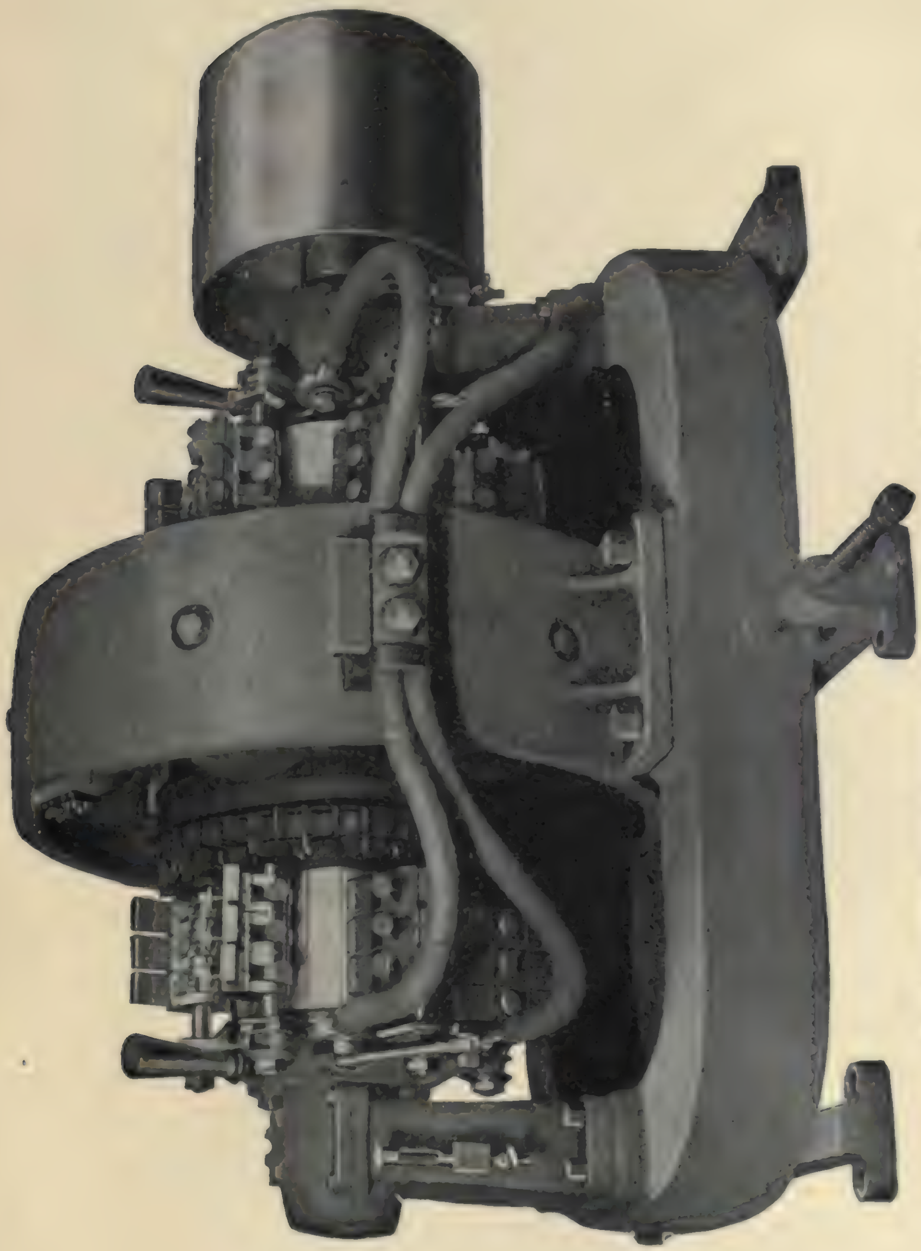

Fig. 43. General Electric Generator for Electrolytic Work. Nos. 3 and 5 DV, Type VI.

and non-magnetic binding wires. The commutator segments are drop-forged copper in the smaller sizes and hard-drawn copper in the larger sizes. The shaft is of crucible steel with the bearings of hard phosphor bronze, self-aligning and self-oiling, while the pedestals are bolted to the base. By changing the windings and modifying the commutator and brush constructions, these frames are adapted to plating generators, as shown in Fig. 45. They are made to deliver from 35 to 1,400 amperes at 6 volts, when running at speeds from 1,300 to 600 R. P. M.

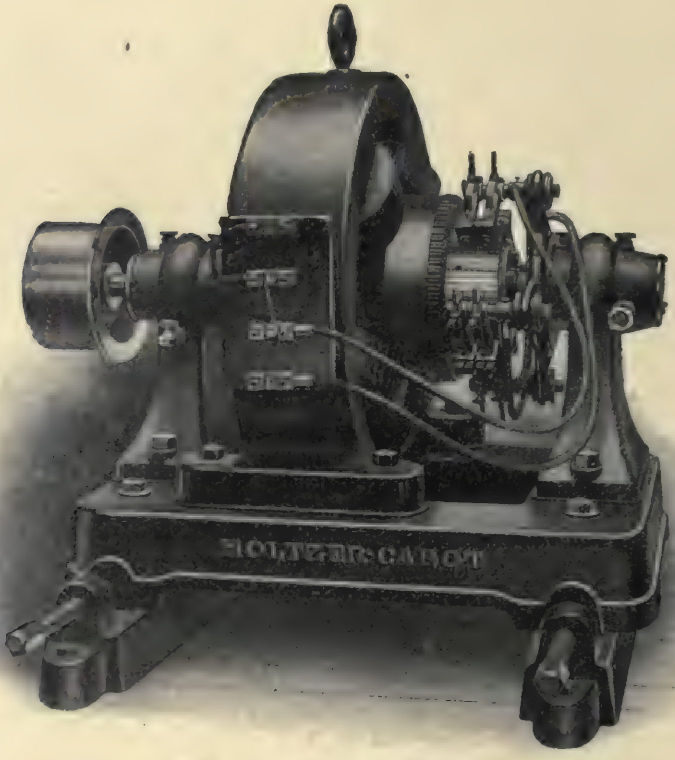

Fig. 44. Holtzer-Cabot Generator.

Northern Electrical Mfg. Co. This company, now controlled by the Fort Wayne Electric Works, builds a line of engine-type generators from 25 to 1,000 K. W. that are wound for any speeds suitable to the various types of engines and furnish any of the standard voltages. These are illustrated in Fig. 46. The field

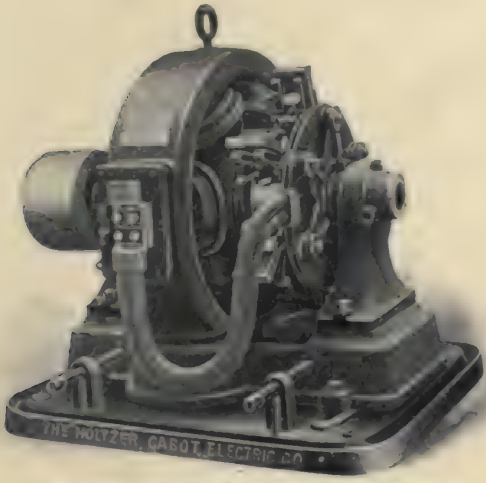

Fig. 45. Holtzer-Cabot Plating Generator.

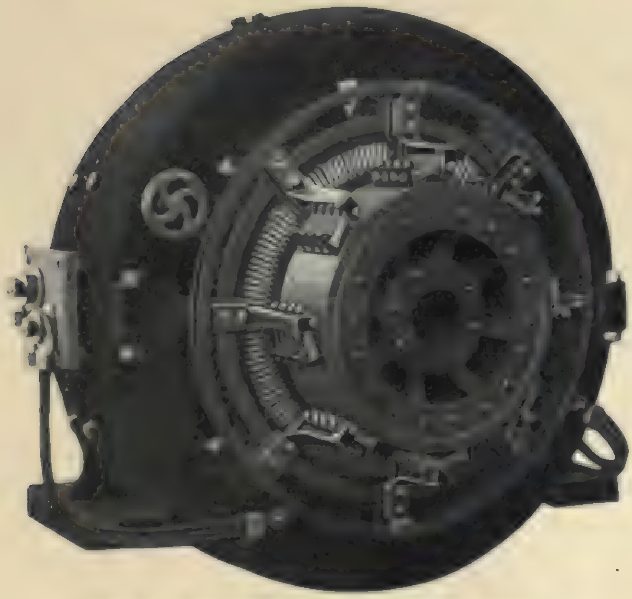

Fig. 46. Northern Electric Multipolar Generator.

frame or ring is made of cast iron in two parts, divided horizontally. Its cross-section is a modified ellipse, being flat on the inside and furnishing a machined surface on which to seat the poles. The pole pieces are specially shaped laminations, shown in Fig. 47, solidly clamped together and bolted to the frame. The diagonal slots trisect the pole and keep the flux in the tips stable, decreasing the shifting of the lines of force and the demagnetization of one of the tips due to armature reaction. By alternately reversing the laminations (which are not symmetrical at the tips) in groups of four or five, a toothed effect is secured, tending to saturate the tips and provide a fringe of lines of force helping commutation. The field coils are rectangular, form wound, and of such dimensions as to provide ventilating ducts between the coils and the sides of the poles. The shunt and the series coils are wound separately and mounted on the poles with an air space between them. The armature spider is of cast iron, in one piece, and carries the commutator spider. The armature is of the laminated, slotted drum type, well ventilated. The spacers are made of U-shaped steel pieces, riveted to the laminations, shown in Fig. 48. The armature coils are formed upon cast-iron moulds from copper bars and have no joints except where attached to the commutator risers. The coils are effectually insulated from each other in addition to the

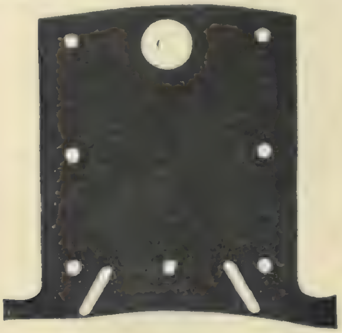

Fig. 47. Pole Laminations of Northern Generator Showing Trisected Feature

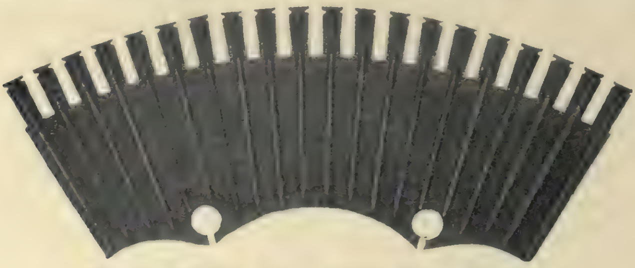

Fig. 48. Northern Armature Ventilating Disk. U-Shaped Steel Stampings Riveted to Disk Act as Spacers.

use of insulating troughs being placed in the slots. In the larger machines the troughs are folded over the top of the coil and covered by hard fiber wedges driven into grooves in the tops of the teeth, thus retaining the coils in the core. One of the armature segments is shown in Fig. 49. In the building of the commutator, brush rigging, brush holders, and equalizing rings, the same care in assembling and in the quality and finish of the material is exercised as in the other parts of the machine already noted. These machines, when furnished with collector rings and compensators, become three-wire generators in all the 250-volt standard ratings. This company's line of belt-driven machines range from $\frac{1}{10}$ to 75 K. W. and in

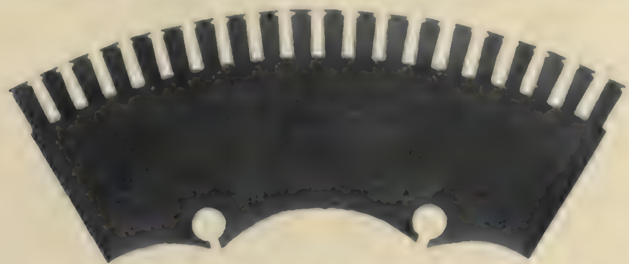

Fig. 49. Armature Segment of Northern D. C. Generators.

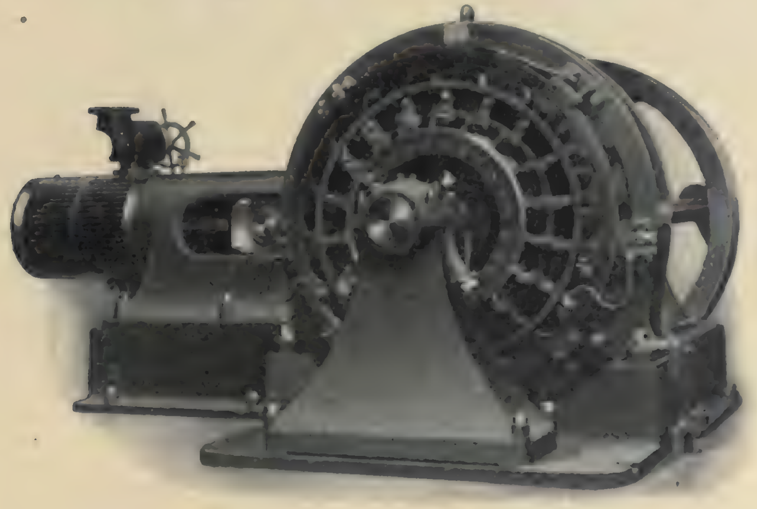

Fig. 50. Ridgway 400-K. W., 550-Volt Generator.

all standard voltages. Their most prominent features are: Cast-steel frames, removable solid steel poles of round section, bronze bearings, cast-iron bonnets, cast-iron bases with belt tighteners, form wound, taped field and armature coils, hard drawn commutator bars.

Ridgway Dynamo and Engine Company. This company manufactures complete engine-driven units and also belted generators from 10 to 600 K. W. in the three standard voltages of 125, 250, and 550, illustrated in Figs. 50 and 51. These machines, in addition to employing the usual methods and materials of high grade generator construction, have several distinguishing features. By employing balancing coils these generators secure sparkless commutation at all loads with fixed brushes. The field ring with solid pole pieces is of annealed cast steel, channel shaped in section, to give the required stiffness with the small amount of metal used in the magnet yoke. The shunt field coils are form wound and placed on the pole necks as usual. Inside of this is a laminated bushing ring, called the *pole ring.* The balancing coils, taking the place of the series coils in an ordinary compound generator, are of copper ribbon, carefully insulated and wound in place by hand through slots in the pole ring. This construction is shown in Fig. 52. These coils are connected in series

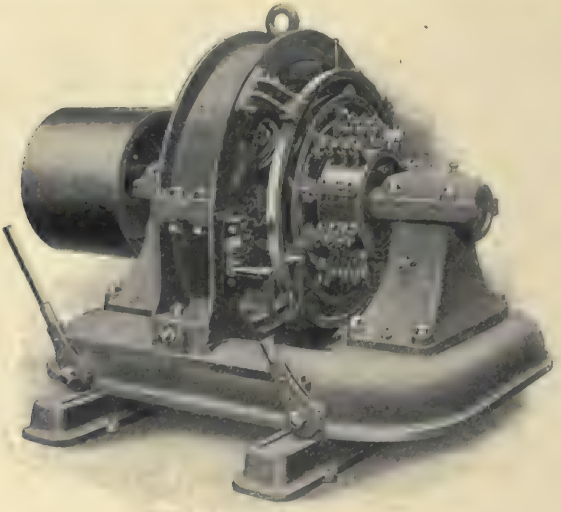

Fig. 51. Ridgway 150-K. W., 250-Volt Belted Generator.

with the armature and are so adjusted, since the current flows through them in the opposite direction to that in the underlying armature conductors, as to neutralize armature reaction. A portion of the balancing coil is wound about a lug in the pole ring so as to set up a secondary field between the pole faces at the place where the short-circuiting of each armature coil takes place. This field depending upon the current output of the machine occasions sparkless commutation. Winding the coils eccentrically and also adding a few extra turns, produces a compounding effect.

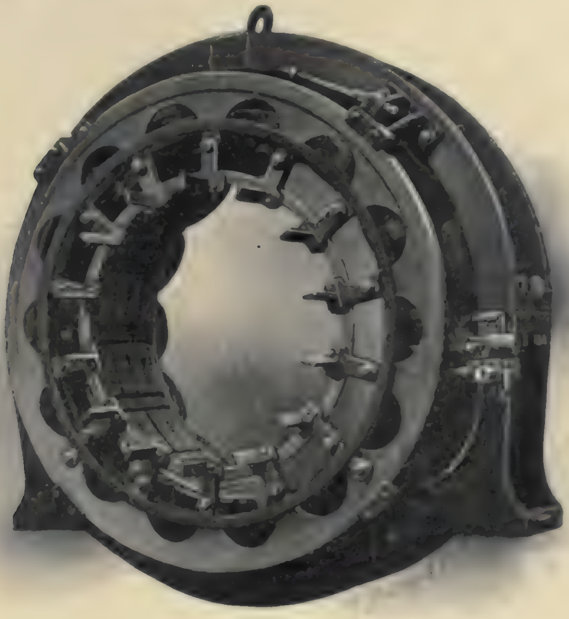

Fig. 52. Ridgway Pole and Field Ring.

Sprague Electric Company. Fig. 53 shows one of the Sprague engine-type generators. They are made in standard sizes from 25 K. W., running at 310 R. P. M. up to 200 K. W. at 200 R. P. M., and in larger sizes when demanded. They employ a horizontally split steel casting for the frame with laminated bolted-in poles, and an ironclad, well-ventilated toothed armature with formed one-piece coils. The pole pieces are specially shaped to prevent armature reaction and give proper flux density in the air gap. The field spools consist of an insulated sheet-iron body with substantial fiber heads. Upon this is first wound the series coil formed of flat copper strip. The shunt coil of insulated copper wire is then wound on the same spool, but separated from the series coil by insulation and half an inch air space, communicating with the outside air through holes in the fiber heads. The commutator consists of hard drawn copper segments, insulated with mica and clamped by a cast-steel ring to a cast-iron shell rigidly supported by the armature spider. Thick mica cones insulate the segments from the clamping ring. The brush holders are liberally designed as regards their current capacity and do not utilize the tension springs for carrying current. The brush holders are supported by a cast-iron rocker ring that fits into a machined seat on the magnet yoke and is capable of being rotated for adjusting the position of the brushes by the hand wheel shown.

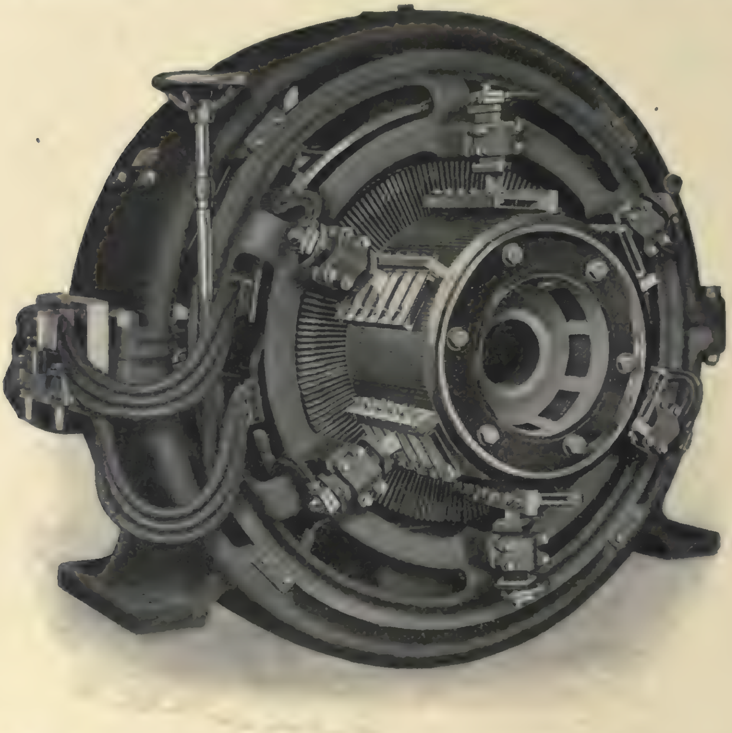

Fig. 53. Sprague Continuous-Current Direct-Driven Generator, 100 K. W., 250 Volts.

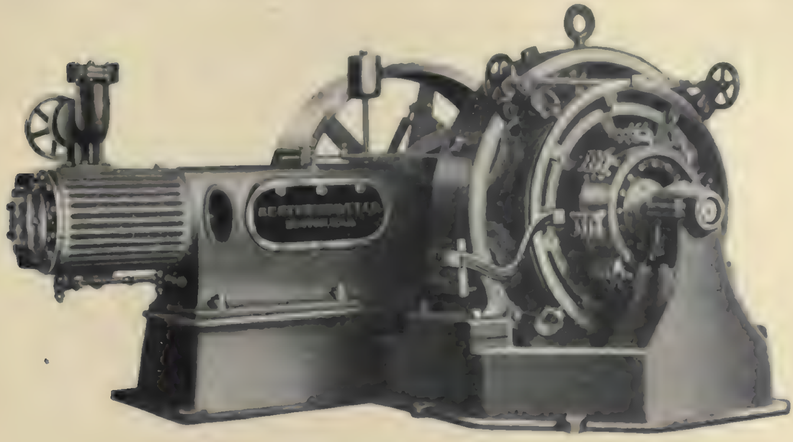

Fig. 54. Sturtevant Direct-Driven Unit.

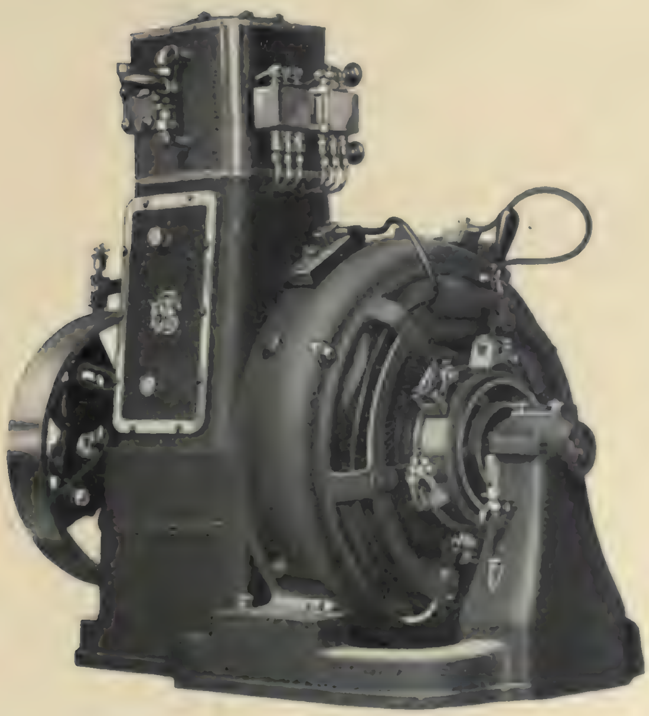

Fig. 55. Sturtevant 5-K. W. Generating Set.

B. F. Sturtevant Company. This company manufactures both the steam engines and the generators of their direct-driven units. These lines of units comprise an engine-type generator in capacities from 20 K. W. at 375 R. P. M. up to 150 K. W. at 250 R. P. M., all eight poles. Their generating sets employ several different types of vertical engines, and range from 3 K. W., direct connected, 6 pole, 800 R. P. M., to 500 K. W., engine type, 10 pole, 160 R. P. M. Figs. 54 and 55 illustrate these types.

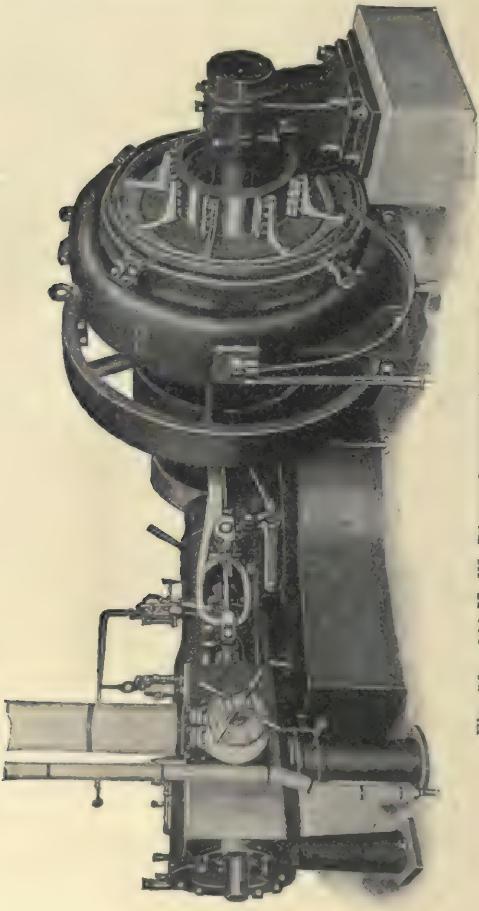

Fig. 56. 200-K. W. Direct-Connected Triumph Generator.

Triumph Electric Company. Fig. 56 shows one of a line of engine-type Triumph generators, ranging in size from 25 K. W., 4 pole, to 300 K. W., 8 pole, and running at speeds from 335 to 100 R. P. M. The frame is of close-grained cast iron, parted vertically, with laminated pole pieces cast welded into it. The field coils are form wound and separated by spacers between them, as shown in Fig. 57. They also build a line of generating sets of the marine type, as shown in Fig. 58, in sizes from 4 to 17½ K. W., all 4-pole

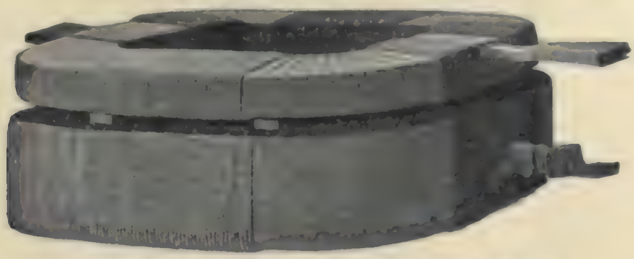

Fig. 57. Triumph Shunt and Series Field Coils.

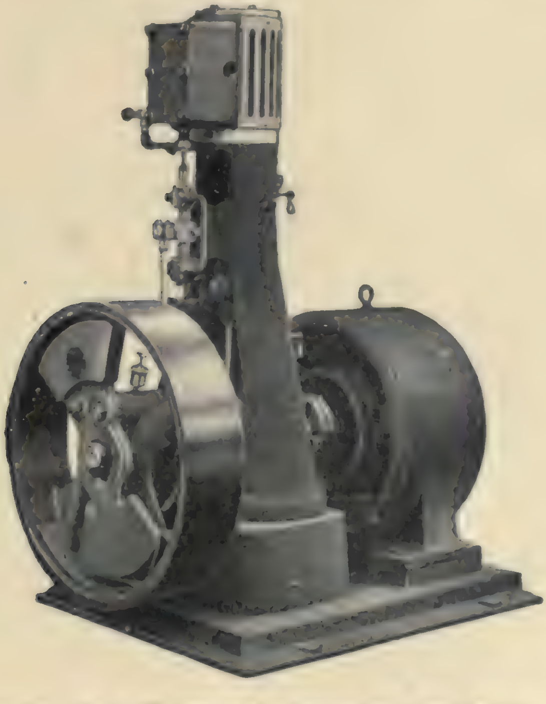

Fig. 58. 17½-K. W. Triumph Generating Set—Troy Engine.

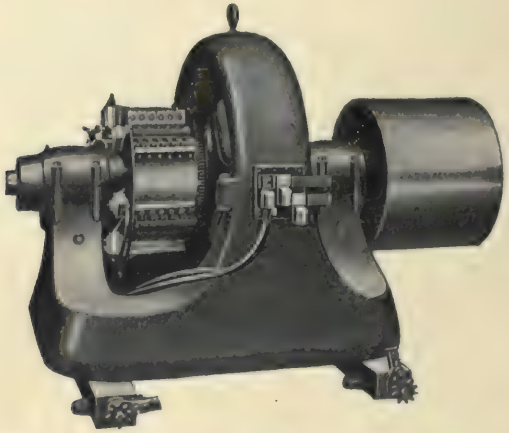

Fig. 59. Triumph Two Bearing 150-K. W. Generator.

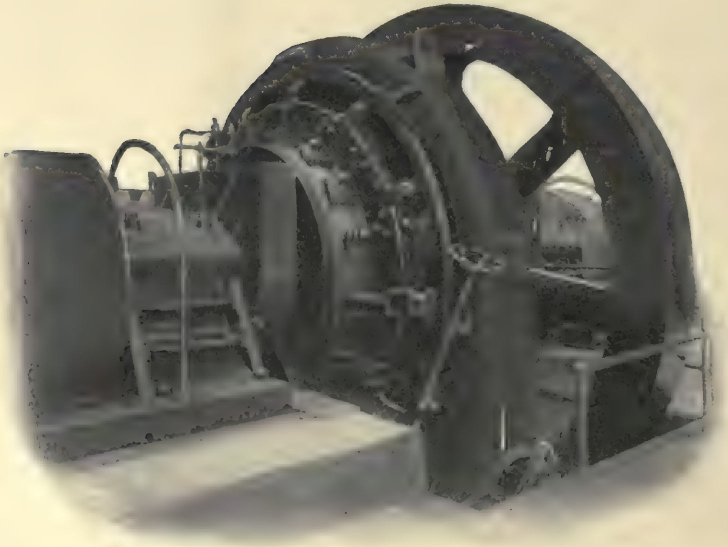

Fig. 60. Western Electric 850-K. W. Generator, 250 Volts, 90 R. P. M.

machines and running at 500 to 350 R. P. M. Their line of belted machines ranges from 3 K. W., 4 poles, at 1,300 R. P. M., to 150 K. W., 6 poles, at 500 R. P. M., and is illustrated by Fig. 59. This company's lines show no special features that have not been previously described under the other manufacturers.

Western Electric Company. Fig. 60 shows an 850-K. W. machine of the engine type placed upon the market by this company. In their standard construction, the frame is divided vertically, made of cast iron in the larger sizes to obtain the needed mechanical strength due to the larger yoke cross-section, and cast steel in the smaller. The annealed mild steel, laminated pole pieces are cast welded in the frames. The shunt and the series field coils, although separately wound and insulated, are mounted on a single metallic spool in ventilated construction. The armature is of the iron-clad, well-ventilated type. The armature windings are one-piece solid bars, insulated individually and in groups, and are retained in the slots by fiber wedges. Any one of their 250-volt engine-type generators becomes a three-wire generator without using a compensator by having a doubly wound armature to obtain the neutral potential point. Use is made of a special balancing winding which is placed beneath the usual armature winding at the bottom of the slots. This winding is interconnected with the main armature winding and a collector ring, insulated from, but mounted at the end of, the commutator, so that the collector ring always possesses a potential midway between the two brushes. The neutral wire is connected to brushes resting on the collector ring. In order to compound for the total load under all conditions, the series field winding is divided in two parts, half the coils (those on every

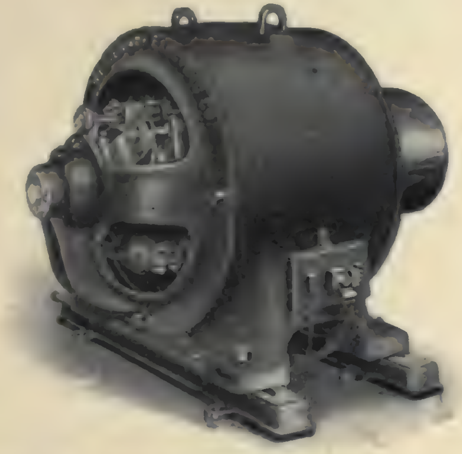

Fig. 61. Western Electric Belt-Driven Generator.

other pole) being connected to one brush and the others to the other brush. This arrangement results in balanced magnetic and electrical circuits. Their belt-driven machines are made in sizes from a fraction of a kilowatt up to 60 K. W., in the form shown in Fig. 61.

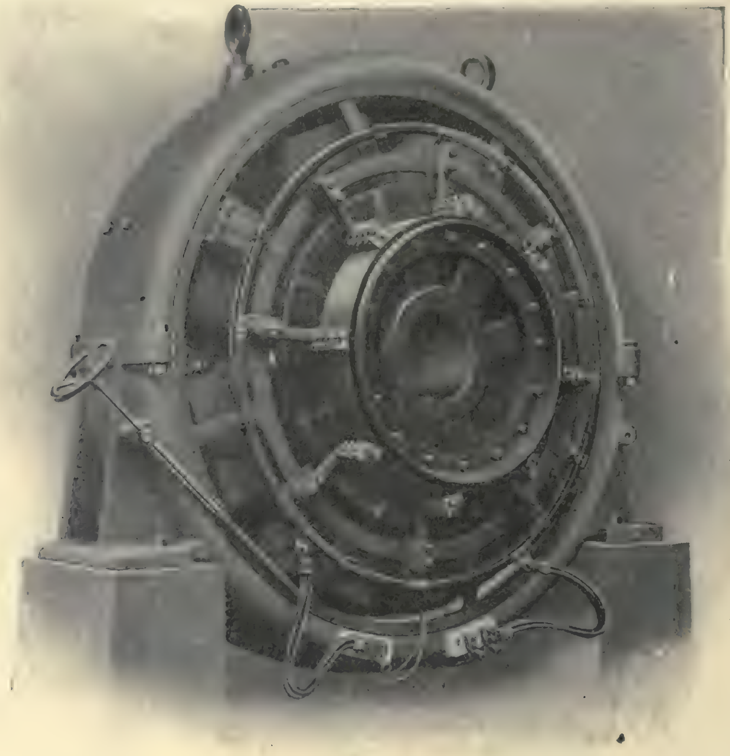

Fig. 62. Westinghouse 350-K. W. Direct-Current Engine-Type Generator.

Westinghouse Electric & Manufacturing Co. This company places upon the market complete lines of engine-type generators of 125, 250, and 550 volts; a 350-K. W. generator is shown in Fig. 62. The magnet yoke is circular and of cast iron. In sizes below 25 K. W. it is in one piece. In sizes from 25 to 125 K. W. it is divided vertically, while for the larger sizes it is divided horizontally. Laminated pole pieces are through bolted to machined seats on the inner surface of the yoke. The pole tips are spread to provide a commutation field and also to secure the field coils. The shunt and the series coils are separately wound with air spaces between them. The series coils are insulated, rectangular, forged-copper conductors. The shunt coils are wire, machine-wound, taped, and rendered moisture proof. The field coils are mounted directly on the pole cores, leaving air spaces, as shown in Fig. 63, no spools being employed. The armature core is built of toothed, sheet-steel stampings on a cast-iron spider that also carries the commutator and the ventilating vanes. The armature coils are machine formed, carefully insulated, and held in place by fiber wedges. Balancing or equalizing rings are provided. The commutator bars, made accurately to gauge, are of hard drawn copper. The brush-holder mechan-

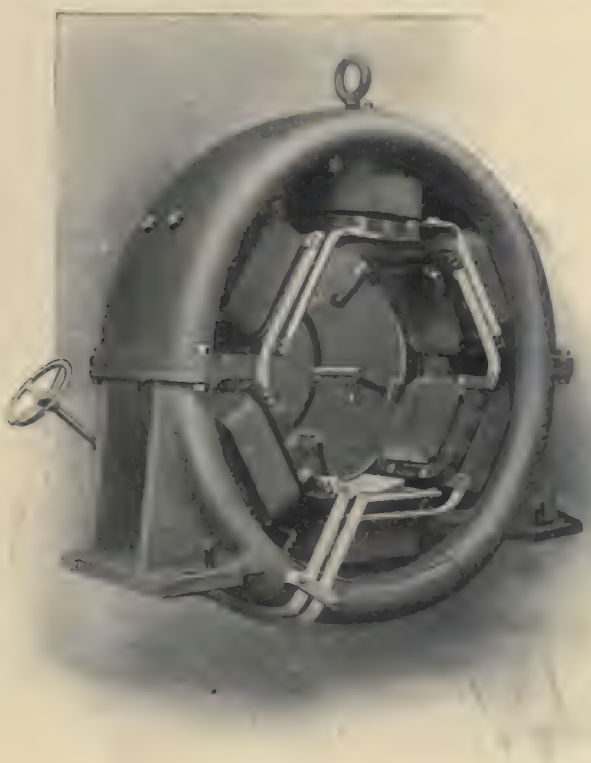

Fig. 63. Field For 250-K. W. 250-Volt Direct-Current Westinghouse Engine-Type Generator.

ism is carried by brackets mounted on a rocker ring carried on a machined seat on the field frame. The brush holder is of the sliding type with copper connections from a clamp on each brush to a solid part of the holder. Copper plated carbon brushes are used in all cases. This company builds a line of self-contained generators in standard sizes from 100 to 300 K. W. at 250 and 550 volts, and 100 to 200 K. W. wound for 125 volts. They are adapted for belt driving or for direct connection where frames with bearings are desired. They embody the same features as and closely resemble in appearance their engine type. Fig. 64 shows the details of the bearings used. The pedestals are bolted to the bed plate and support self-oiling bearings that consist of cast-iron shells lined with babbitt metal and lubricated by means of rings that ride upon the shaft and dip into large reservoirs in the pedestals, filled with oil. The rings, rotated by the motion of the shaft, continually bring up a supply of oil. Another line of machines, designated type *S*, furnishes the smaller sizes. The methods of manufacture and materials for the various parts are the same as in the other lines, but the outward appearance is entirely different, since the bearings are supported by brackets of the skeleton type with radial arms and an outer ring bolted to the frame. The standard belted machines range from 2 to 85 K.-W. for 125 and 250 volts, and from 3½ to 75 K. W. at 550 volts. These generators may also be direct connected, forming generating sets as shown in Fig. 65. When direct connected they require special windings and the capacity of any frame changes, the output being roughly proportional to the speed of the armature.

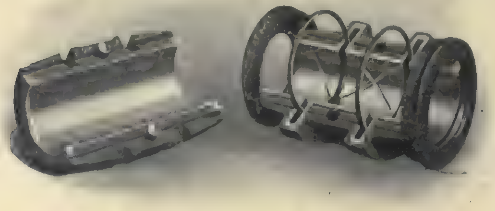

Fig. 64. Bearing of Westinghouse Direct-Current Self-Contained Generator.

Another line, called type *R*, gives 8 sizes from ¾ to 7½ K. W.; the smallest 4 sizes being bipolar, the others 4 pole. These are intended for belt driving, although the multipolar frames can be adapted for direct driving. The details of construction are shown in Fig. 66. Any engine type, any self-contained, and any type *S* generator above 5 K. W., provided the voltage is 250 or 550, may, by the addition of properly connected collector rings, become a three-wire generator. The Westinghouse Company prefers the two-phase arrangement. This necessitates four collection rings, as shown in Fig. 67. It further requires two compensators or autotransformers. These consist, each of a single winding upon a laminated core

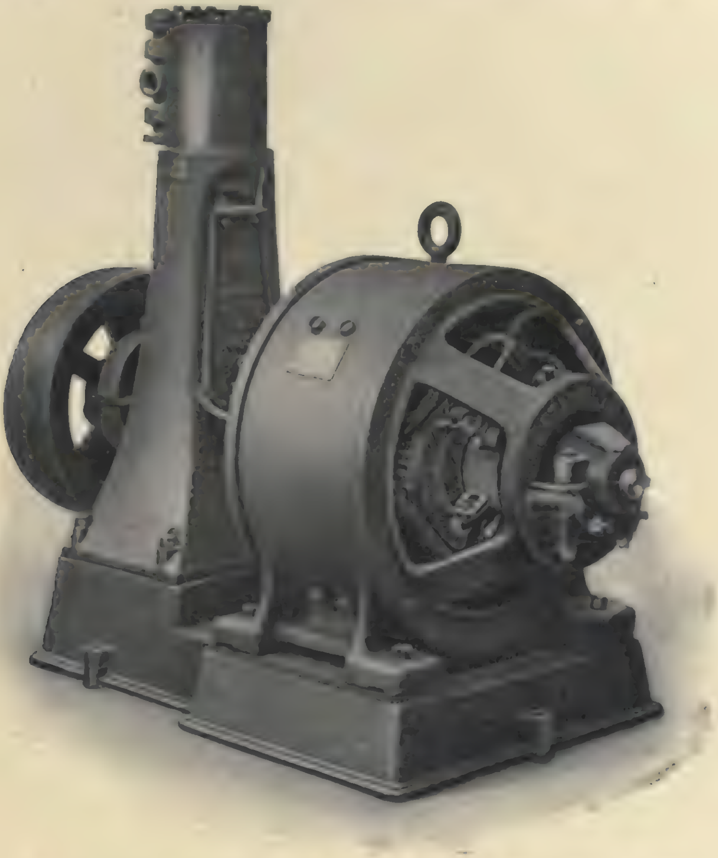

Fig. 65. Westinghouse Generating Set—Type *S* Generator Driven by A B C Engine.

and are each connected to two of the collector rings. The middle points of the autotransformers are connected together and to the neutral of the three-wire system. Fig. 68 shows a Westinghouse direct-connected generator for electrolytic work. It is shunt wound with an output of 4,000 amperes at a few volts. At this large amperage and low voltage, special construction is necessary to keep down the contact resistance at the commutator. To accomplish this, the machine carries two commutators, each of very large area and with a large number of brushes. There is only one armature winding, with both commutators connected to it. The circuits derived from the two commutators may be kept separate or connected in parallel.

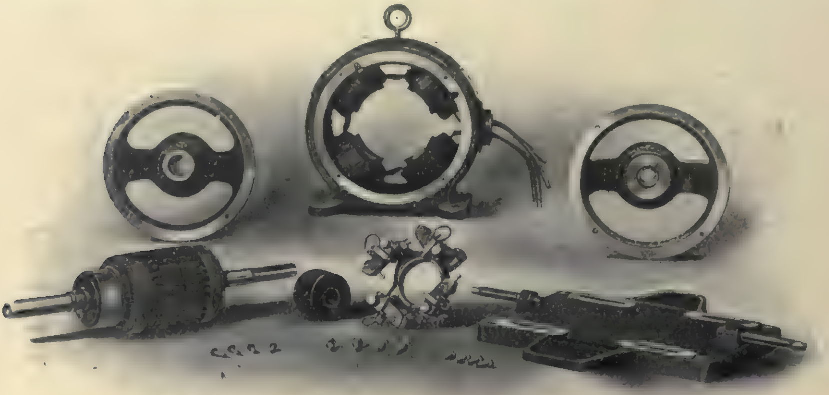

Fig. 66. Parts of Multipolar Westinghouse Type *R* Generator.

MOTORS

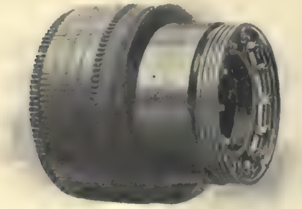

Fig. 67. Armature of 300-K. W. Westinghouse Three-Wire Generator.

The standard practice at present with respect to the use of electric motors favors the direct method of driving. Therefore, many motors, especially those running at constant speeds, are identical in appearance as regards their general outlines to direct-driven generators.

In fact, manufacturers actually employ the same frames for generators and motors, merely changing the windings to produce the required characteristics. Motors for direct driving are now commonly mounted upon the shafts of lathes, boring mills, drill presses, shapers, punching machinery, hydrostatic presses, laundry machinery, traveling cranes, pumps, mine hoists, and many other classes of machinery. Many prominent printing plants are now operated by motors direct-connected to the presses, and this system of direct driving is also applied to many of the great mills, factories, and steel works. The employment of electric motors in place of belting and shafting in factories results in a large fuel economy, in increased output of the manufactured products, in

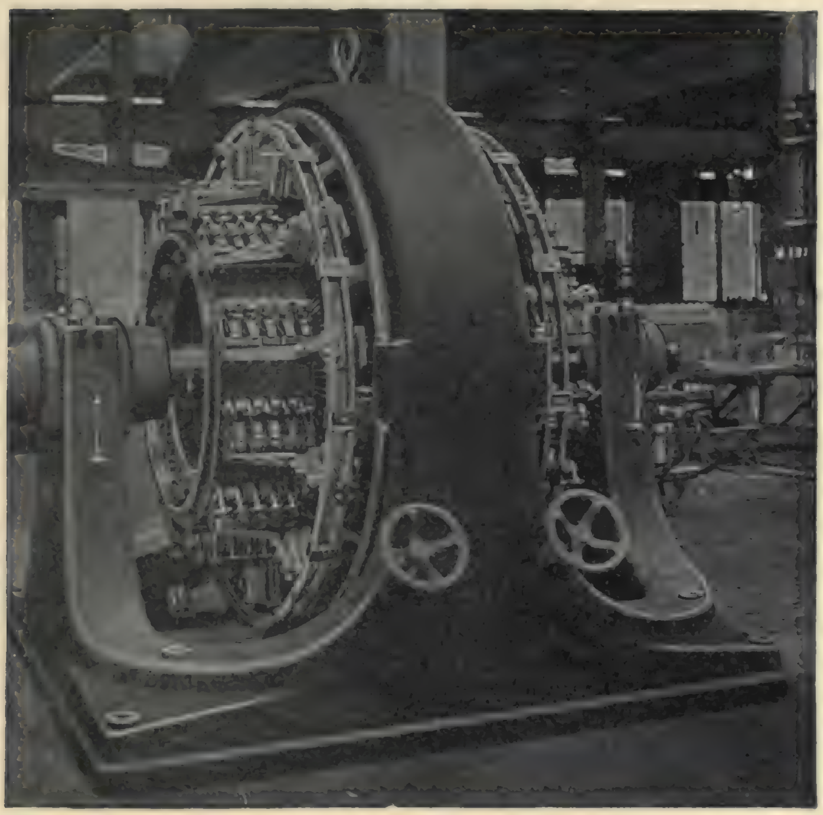

Fig. 68. Westinghouse Direct-Current Generator with Two Commutators for Electrolytic Work.

flexibility as to location of machinery, and in better speed regulation. The only objection is the greater first cost. The fuel economy is due to the elimination of losses due to shafting and belting and to the fact that the consumption or energy entirely ceases when the tool stops. The increased output is secured by the greater convenience in starting and stopping as well as in regulating the speed of the machinery.

Direct-current motors are either shunt, series, or compound. A shunt motor runs at practically constant speed for all loads, has a torque almost directly proportional to the armature current, and has a starting torque usually 50 to 100 per cent greater than full load running torque. A series motor runs at greatly decreasing speed for increasing loads, has a torque that increases almost as the square of the armature current or at least much faster than proportional to it, and has a powerful starting torque. A compound-wound motor approximates the shunt or the series type in its characteristics, depending upon which winding preponderates.

Speed Classification. Direct-current motors according to their speed performance fall into four different classes:

1. *Constant-speed motors,* in which the speed is either constant or does not materially vary, as shunt motors and compound motors in which the shunt field preponderates.

2. *Multi-speed motors* (two-speed, three-speed, etc.), which can be operated at any one of several distinct speeds, these speeds being practically independent of the load, such as motors with two armature windings.

3. *Adjustable-speed motors,* in which the speed can be varied gradually over considerable range; but when once adjusted remains practically unaffected by the load, such as shunt or slightly compounded motors designed for a considerable range of shunt field variation.

4. *Varying-speed motors,* or motors in which the speed varies with the load, decreasing when the load increases, such as series motors and compound motors in which the series winding preponderates.

Classification According to Uses. The various kinds of work demanded of electric motors fall into six classes, necessitating particular types as follows:

a. Work that requires the motor to run at practically constant speed independent of the load, as in a line shaft running several machines but driven by a single motor. This class of work employs a constant-speed motor and regulates automatically.

b. Work that requires frequent starting and stopping and extremely small initial acceleration, as in the operation of printing presses and gun turrets. Here a multi-speed motor or a constant-speed motor with a multi-voltage system is employed, requiring continual hand control.

c. Work that requires varying power at different set speeds, as in machine tool service. Adjustable-speed motors answer to these requirements.

d. Work in which the required torque increases with the speed, as in centrifugal pumps, fans, or blower equipments. Varying-speed motors are used here and in this case regulate automatically, speeding up until the exerted torque equals the required torque. Constant-speed motors are also used provided their full load torque is as great as that required at maximum demand.

e. Work requiring frequent starting and stopping with greatest torque at starting, as in electric traction and crane service. For this class of work series motors are employed and require hand control.

f. Work that in addition to frequent starting and stopping calls for a speed independent of the load after rapid acceleration, as in elevator service. These exacting conditions are fulfilled by a heavily compounded motor. At starting the series winding preponderates, but is not so strong at full speed or may even be short-circuited and the motor then acts as a shunt machine. This service can also be performed by adjustable-speed motors fitted with interpoles.

Description of Types. *Allis-Chalmers Company.* The larger constant-speed motors of this company employ the same frames as their belted generators shown in Fig. 16. They include many sizes at 120, 240, and 500 volts from 10 to 550 horse-power, ranging in speed from 1,050 to 230 R. P. M. Their type *K* machine, shown in Fig. 69, is built in 13 different frame sizes with a number of ratings for each frame, depending upon the winding and the speed. The smallest shunt-wound constant-speed size in the 120-volt line is $\frac{1}{8}$ H. P. at 1,600 R. P. M., and the largest is 80 H. P. at 500 R. P. M.

They are also wound for 240 and 500 volts. They can be used as adjustable-speed motors with a range in speed of 1 to 3. They also can be wound as any type compound or series motors, thus becoming varying-speed motors. The field-magnet yoke is of open-hearth steel and machined on the end to receive the housings that carry the bearings. The housings, held in place by through bolts, can be rotated 90 or 180 degrees. This allows bipolar machines to be mounted on floor or ceiling and 4-pole machines to be mounted on floor, ceiling, or side wall. Fig. 70 shows an Allis-Chalmers type *K* motor mounted on a planer. Standard motors of this type are made open at the ends; they can, however, also be made semi-enclosed

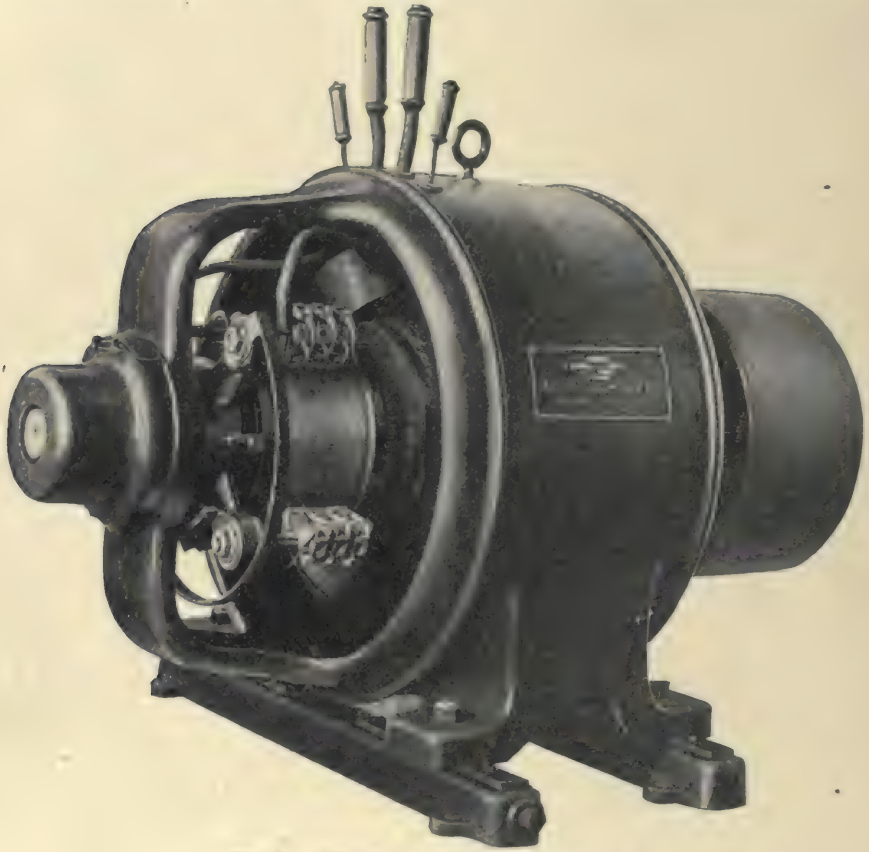

Fig. 69. Allis-Chalmers Type *K* Motor.

and totally enclosed by the addition of suitable metal enclosing covers fitted to the end housings. The semi-enclosed type uses perforated covers forming a screen that, while allowing a circulation of air, protects the motor from flying particles. Totally enclosed motors are dust and moisture proof. This shuts off the ventilation, and the output of a given frame is less for the totally enclosed type than for the others. The enclosed motor does well, however, for intermittent work where it has ample time to cool in the intervals of work. This company also manufactures a line of railway motors of 35-, 50-, and 75-H. P. capacities to be used on circuits from 500 to 650 volts. Fig. 71 illustrates the 35-H. P. size thrown open. The cast-steel field frame is in two parts, divided horizontally through the bearings. This motor is of the series, 4-pole type, dust and moisture proof.

Garwood Electric Company. This company employs the frames of their line of standard belted generators, shown in Fig. 19, for constant-speed motors of the larger sizes. These machines are wound for 125, 250, or 500 volts, ranging from 30 to 250 H. P. at many different speeds between 570 and 220 R. P. M. Their type *SL* machines, illustrated in Fig. 20, give rise to constant-speed motors ranging from $1\frac{1}{2}$ to 40 H. P., either shunt or compound. They are wound for 110, 220, 440, 125, 250, or 500 volts. The greatest speed is 1,700 and the lowest 630 for any machine of this design. They are also arranged for ceiling and wall mounting, as well as with vertical shaft. All of these varieties can also be semi-enclosed or fully enclosed. With proper windings they become adjustable-speed motors and are built for a speed variation of 5 to 1. Figs. 72, 73, and 74 are illustrations of these machines. This company also manufactures multi-speed motors with two armature windings and

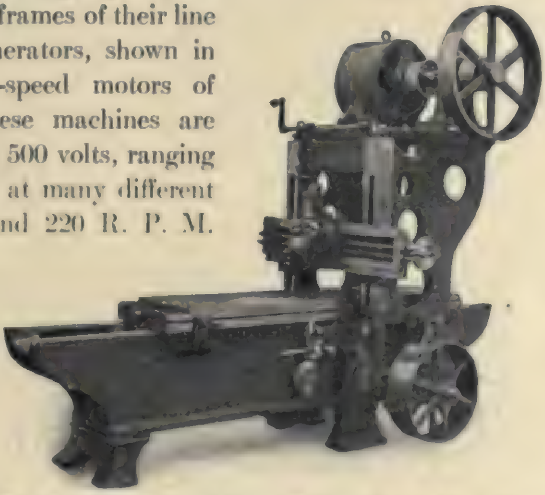

Fig. 70. Allis-Chalmers Type *K* Motor Mounted on 30" x 30" American Planer.

double commutators, as shown in Fig. 75. They are used for running printing presses when equipped with series-parallel method of control. In the large sizes they employ the same frames as their standard belted generators.

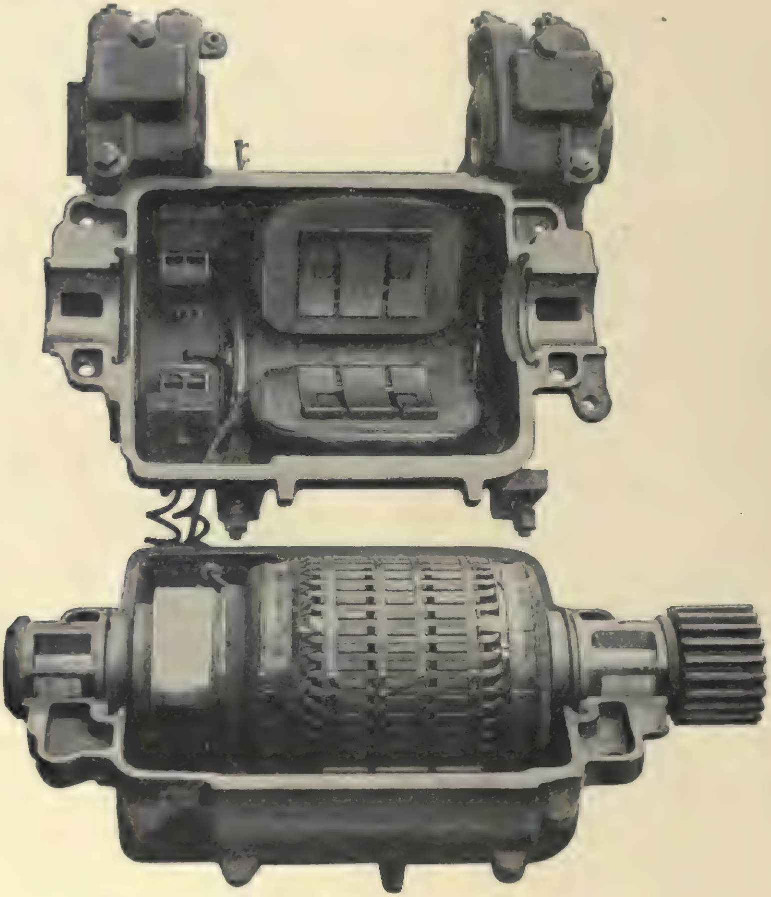

Fig. 71. 35 Horse-Power Allis-Chalmers Railway Motor.

Crocker-Wheeler Company. The larger constant-speed motors running between 870 and 360 R. P. M. and varying from 50- to 275-H. P. capacity are obtained by this company by using their form *D* frames, shown in Fig. 23. They can be wound so as to run on 110, 115, 220, 230, or 500 volts. Their form *I* machines, shown in Fig. 24, give them shunt motors from 2½ to 45 H. P. at any of the above five voltages, the speeds falling between 1,650 and 330 R. P. M. This type of frame can be shunt wound, series wound, or compounded to any degree, as well as furnishing a line of field-weakening adjustable-speed motors giving a speed range of 3 to 1. It also can be arranged for floor, side wall, or ceiling mounting and with vertical shaft. By adding proper covers to the open type it becomes en-

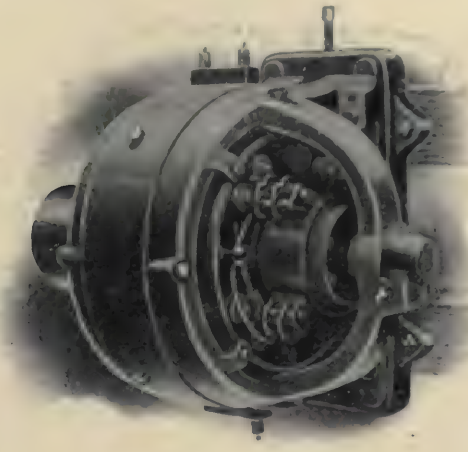

Fig. 72. C & C Open Wall *SL* Motor.

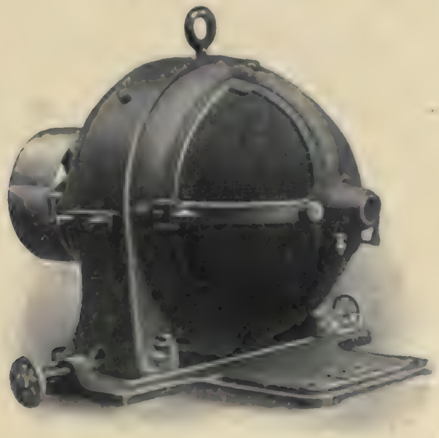

Fig. 73. C & C Semi-Enclosed Gauge Type *SL* Motor.

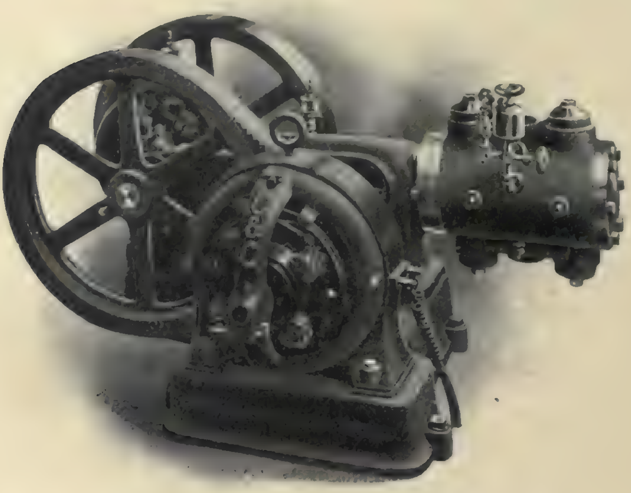

Fig. 74. C & C Type *SL* Motor and Reciprocating Compressor.

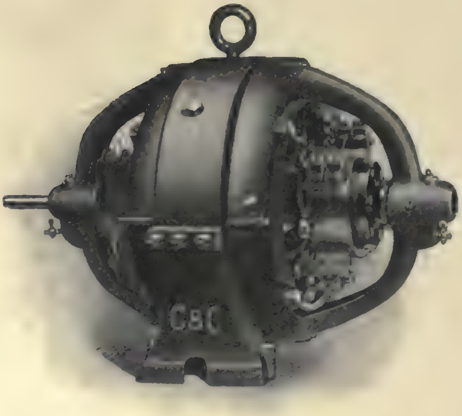

Fig. 75. C & C Double Commutator Type *SL* Printing Press Motor.

closed or semi-enclosed, the latter either grid or gauze. Enclosed motors are particularly adapted to operate in flour mills, wood working shops, boiler rooms, machine shops, etc., where the air is continually filled with fine particles. Being almost air tight, they are larger frame for a given output than open, ventilated motors; but with proper windings and frame they may be of practically the same efficiency as the open types. They are not very well adapted for continuous running, but do admirably for intermittent service. This company brings out a line of slow-speed, constant-speed, direct-connected motors having no shafts of their own. A motor of this line is intended to be keyed directly onto the shaft of the machine it is to drive, as shown in Fig. 76. They are designed for 220- to 230-volt circuits, ranging from 28 to 450 H. P. The highest speed is 350 and the lowest 83. These low speeds are possible by increasing the number of poles, they being from 6 to 12. Slow-speed motors have a smaller power output for a given weight than the high-speed types. This does not mean that their efficiency is lower, but that for a given horse-power rating, the slow-speed motor is the heavier

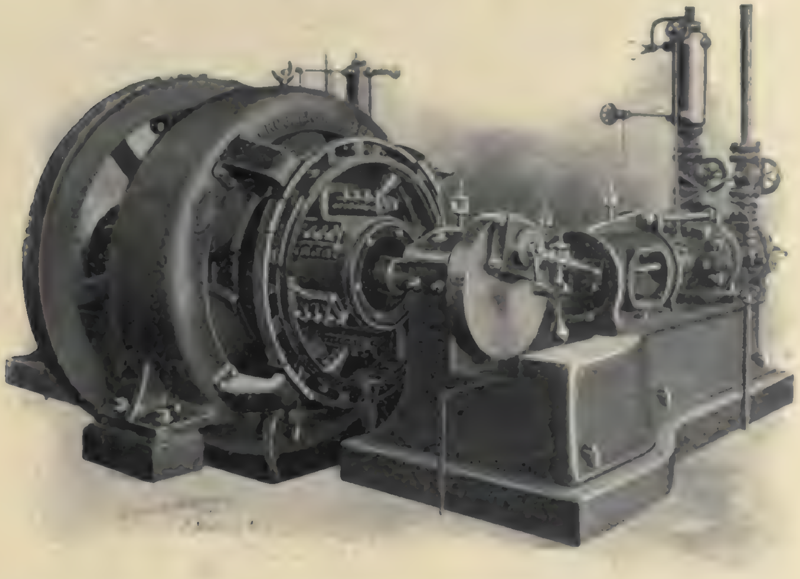

Fig. 76. Crocker-Wheeler 40-H. P., 230-Volt Motor Driving Ammonia Compressor.

and the larger. From this it follows that its cost per horse-power is greater. On the other hand, the slow-speed type runs cooler, has better mechanical construction, and stands long, continued overloads much better. For the smaller sizes, this company uses a 2-pole motor called by them form *L*. They are made in sizes from $\frac{1}{20}$ to 5 H. P. for operation on 115-, 230-, or 500-volt circuits and are suited for application to all sorts of light machinery. Fig. 77 shows one of the many uses. To supply the demand for traveling crane motors, this company has developed a line of motors shown in Fig. 78. They are made in sizes from $1\frac{3}{4}$ to 65 H. P., operating on 220 or 500 volts. They are series-wound, compact, of strong and rugged construction, rectangular frame, and are protected against dirt and moisture by enclosing covers. Still another line of motors brought out by this company are their rolling-mill motors, shown in Fig. 79. These motors are built in 9 sizes from $7\frac{1}{2}$ to 200 H. P. intermittent rating, at 220 volts. They are of enclosed construction with an octagonal steel crane. They are 4-pole series or compound wound. In the compound form the shunt is light, merely preventing the motor from doubling its speed if the load is removed. All insulation is fireproof and of great structural strength, allowing the motor to withstand outside roasting or internal heating from overloads.

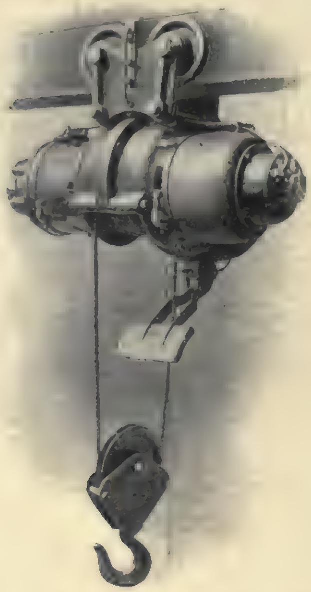

Fig. 77. Traveling Hoist Driven by Crocker-Wheeler Form *L* Motors.

Electro-Dynamic Company. A prominent type of adjustable-speed motor is that of the Electro-Dynamic Company in which speed variations from 6 to 1 may be obtained by field weakening. Sparking is prevented by the employment of interpoles; that is, auxiliary

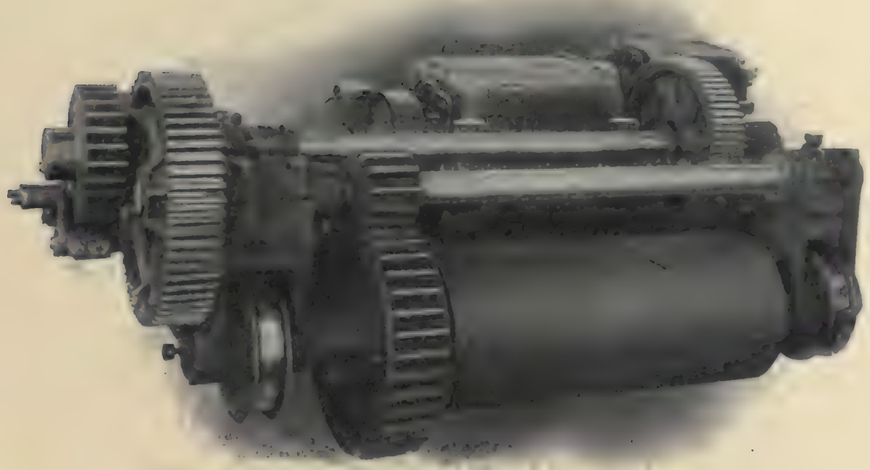

Fig. 78. Crocker-Wheeler Crane Motors on Trolley of Traveling Crane.

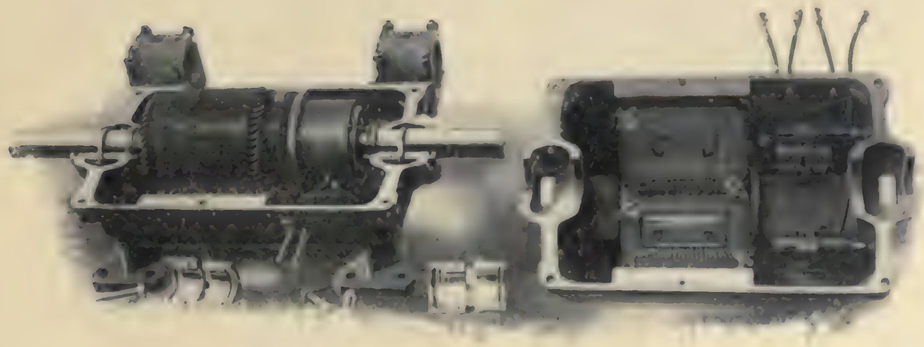

Fig. 79. Crocker-Wheeler Rolling Mill Motor with Top Half Lifted Off

poles, small compared with the main poles, are located between the latter and provided with coils connected in series with the armature. The flux of these interpoles is in direct opposition to that o the armature and gives the commutation field. Since the coils of the interpoles are connected in series with the armature, the commutation field is not affected by weakening the shunt or main motor

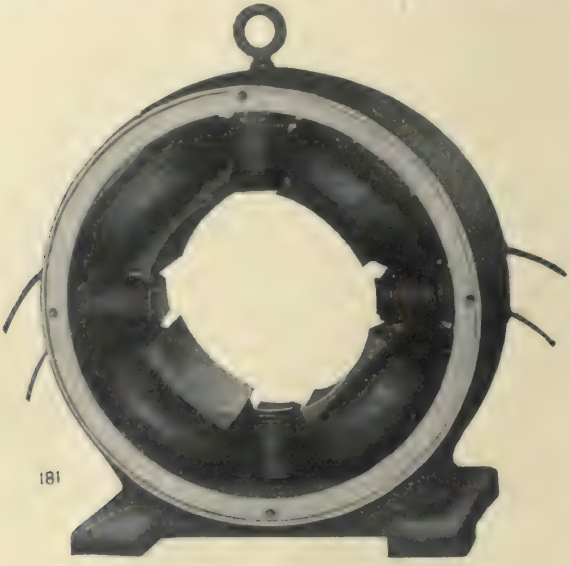

Fig. 80. Electrodynamic Motor Showing Interpoles.

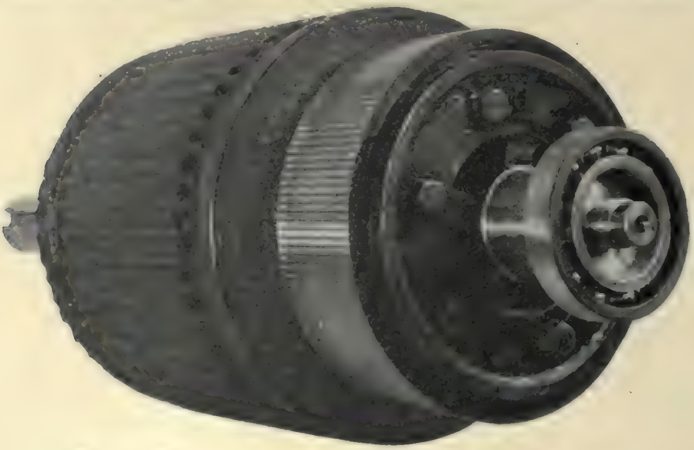

Fig. 81. Interpole Motor Armature Showing Ball Bearings.

field to obtain the increased armature speeds. It is, furthermore, proportional to the load, thus producing sparkless commutation at all loads and speeds within the limits of the design of the machine. As the action of the interpoles is reversible, the motors can be run equally well in either direction. Fig. 80 is a view of one of these motors with the bearing housings and armature removed, showing the interpoles. These motors are manufactured in sizes from ½ to 75 H. P. as 4-pole machines, and in sizes from 40 to 150 H. P. as 6-pole machines, operating on 110-, 220-, or 500-volt circuits.

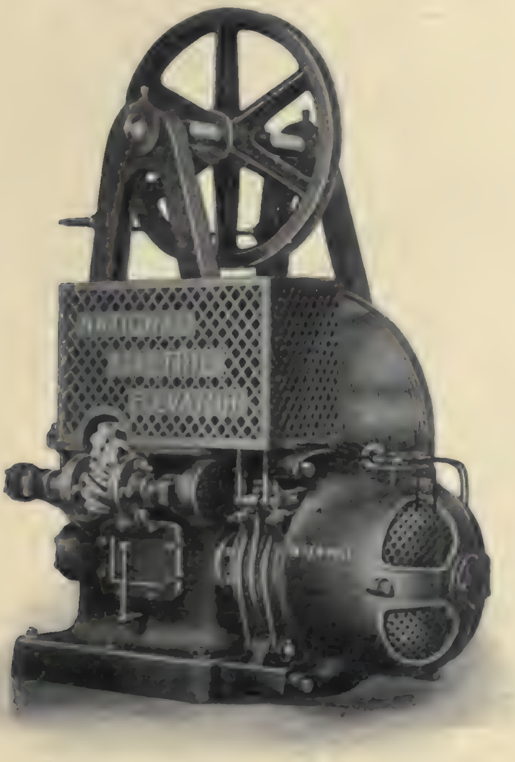

Fig. 82. The Interpole Variable-Speed Motor, as Applied to Electric Elevator Equipment Manufactured by the National Elevator Company.

The field yoke, except in the largest frame, is of best electrical steel in one piece. The main poles are cast steel or laminated, as required, bolted to the yoke, and the interpoles are of wrought iron.

The ball bearings used have two races for the balls, one fastened directly to the armature shaft and the other free in the bearing housing. The kind of bearing is shown in Fig. 81, and since the lubricant is vaseline or other heavy lubricant, the machine can be placed in any position. This motor is, of course, also manufactured in semi-enclosed, enclosed, and vertical types. Fig. 82 shows one of the many applications of this machine.

Fairbanks, Morse & Co. This company manufactures several lines of constant-speed, shunt-wound motors, using the same frames as for their lines of belted generators. The separate motors range from 150 H. P. at 650 R. P. M., like Fig. 29, down to 2 H. P. at 1,800 R. P. M., like Fig. 28. The same frames are also compound wound giving a drop in speed of about 20% between no load and full load. They are wound to operate on 110-, 220-, or 500-volt circuits. Their smaller sizes are made in all the varieties, similar to other manufactures, and also furnish a line of adjustable-speed motors with speed variation of 2 to 1 or 4 to 1, as called for. Fig. 83 shows one of their smaller motors driving an exhaust fan.

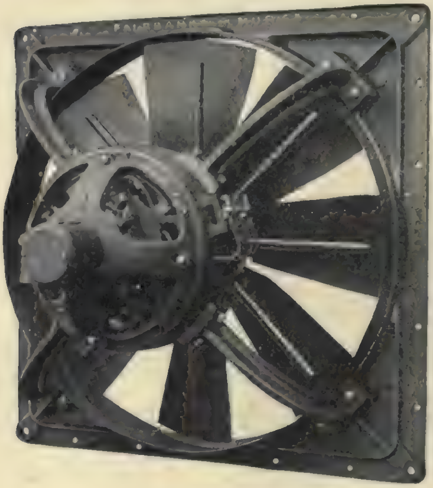
Fig. 83. Direct-Connected Exhaust Fan Driven by Fairbanks-Morse D. C. Motor.

Fort Wayne Electric Works. For the largest direct-connected, constant-speed motors, as would be needed for driving air compressors for instance, this company employs the frames of their engine-type generators, shown in Fig. 31. Their medium-capacity, belted, constant-speed motors from 25 to 105 H. P., shown in Fig. 84, are practically identical with their belted generators. These sizes are 6-pole machines and are made for slow, medium, or moderate speeds operating on 115-, 230-, or 500-volt circuits. Their type *EF* motors, illustrated in Fig. 85, are all 4 pole, ranging from

1 to 70 H. P. Their type *L* motors, shown in Fig. 86, are bipolar and built in sizes from $\frac{1}{4}$ to 2 H. P. Both these types are constant-speed motors, designed to operate at 115, 230, or 500 volts, can be mounted in any of the positions, and can be furnished open, semi-enclosed, or enclosed. A line of very small motors from $\frac{1}{100}$ to $\frac{1}{30}$ H. P. and several fan motors complete this company's direct-current apparatus.

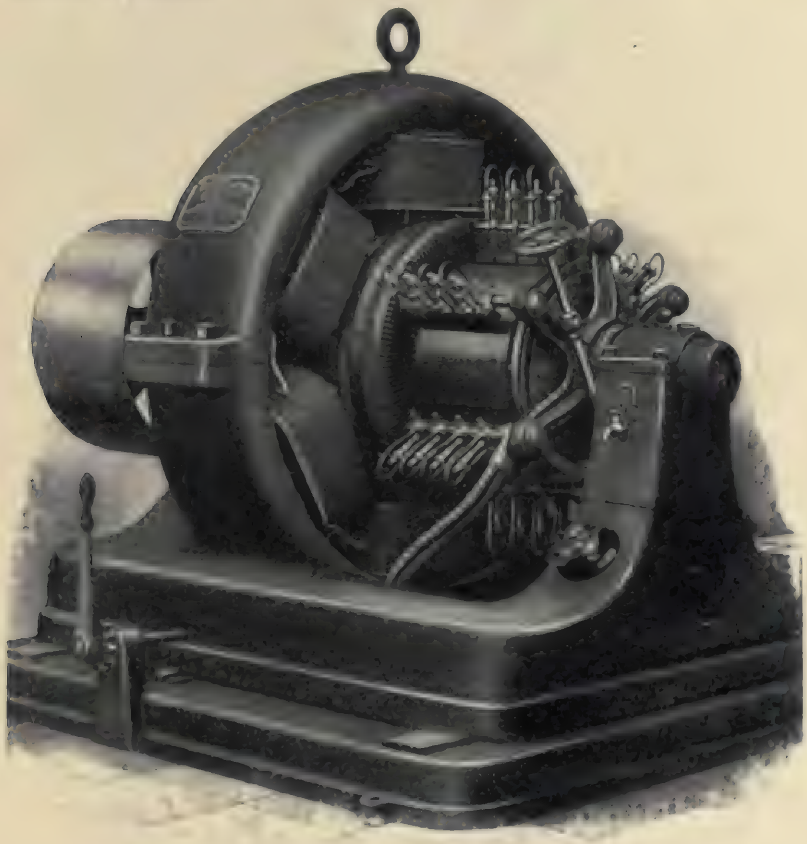

Fig. 84. Fort Wayne 105 Horse-Power Motor.

General Electric Company. Constant-speed motors of medium capacity are manufactured by this company, using the frames of their 6-pole belted generators, shown in Fig. 42. The slow-speed line furnishes sizes from 185 to 20 H. P. and the moderate-speed, from 150 to 30 H. P. When fitted with *interpoles* or *commutating poles*, as the General Electric Company calls them, these machines are wound for adjustable-speed motors with speed variations of 1½ to 1, 2 to 1, or 3 to 1 as desired, in sizes 20 to 130 H. P. intermittent rating. For the smaller sizes, they manufacture a line of motors of the general appearance shown in Fig. 87. This line consists of eleven different frames, the largest three being 4 pole and the other bipolar. They are constant speed, shunt, or compound wound. Wound for slow speeds they range from ¾ to 15 H. P. and for moderate speeds from ⅙ to 15 H. P. The 4-pole frames, when so wound, become adjustable-speed motors with speed variations of 1½ to 1, 2 to 1, or 3 to 1. They then are fitted with commutating poles and become from 5 to 27½ H. P., intermittent ratings. One of these motors is shown in Fig. 88. All of these various lines

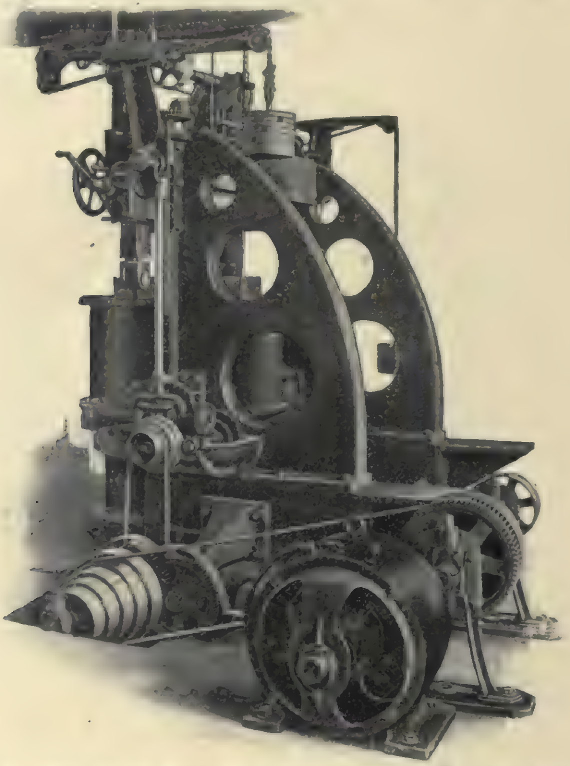

Fig. 85. Fort Wayne Type *EF* Motor Driving Vertical Boring Machine.

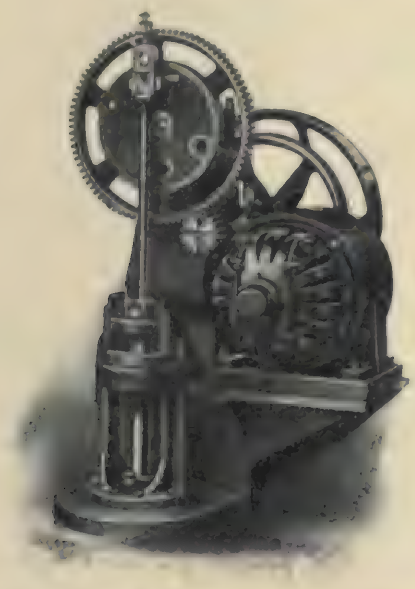

Fig. 86. Fort Wayne Type *L* Motor Driving Pump.

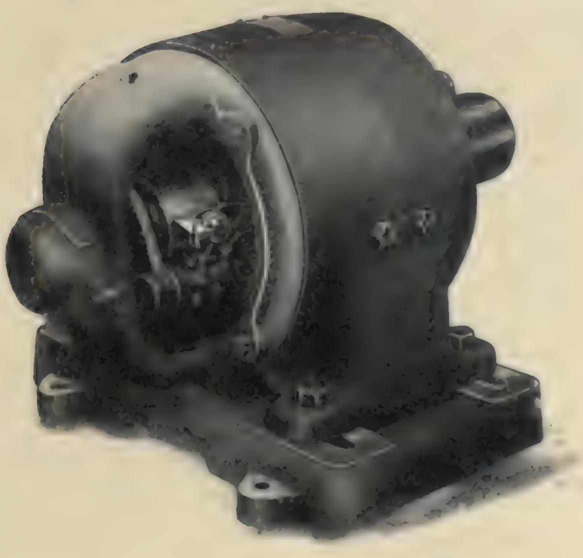

Fig. 87. General Electric 2-H. P. Motor.

are wound for 115, 230, or 550 volts, can be arranged for any desired mounting, and are manufactured as open, semi-enclosed, or enclosed. The direct-current mill motors gotten out by the General Electric Company are enclosed, octagonal frame, and fire-proof construction in 5 sizes from 30 to 150 H. P., at 220 or 500 volts. They are series, shunt, or compound wound as desired. Another complete line of motors is their railway motor, the latest forms of which also

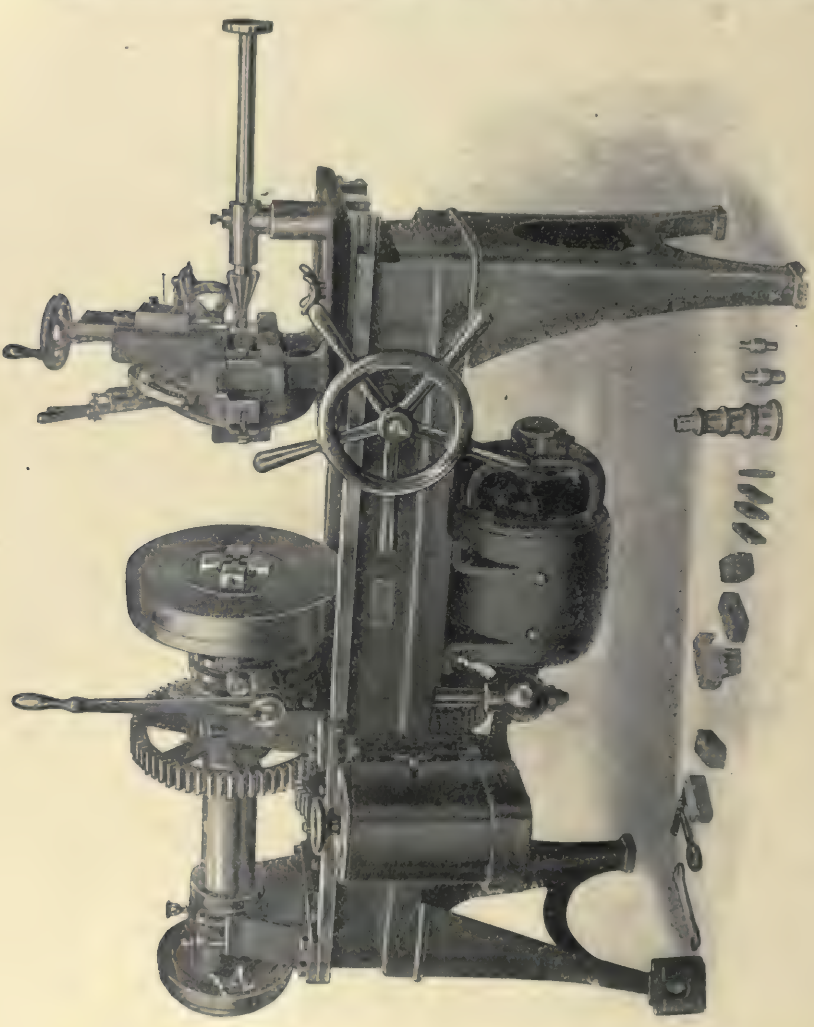

Fig. 88. General Electric Motor Driving Universal Pipe Cutting and Threading Machine.

use commutating poles. They are wound for 600-volt circuits, the construction adopted for this class of machines being clearly shown in Figs. 89 and 90. Besides their larger machines this company also puts upon the market a complete line of fan motors and small power motors from about $\frac{1}{100}$ up to $\frac{1}{10}$ H. P., adapted to a great variety of uses.

Holtzer-Cabot Company. The belted generators manufactured by this company, illustrated in Fig. 44, become, with proper windings, their constant-speed motors of $1\frac{1}{2}$ to 100 H. P. These frames, when employing a heavy compound winding, become varying-speed

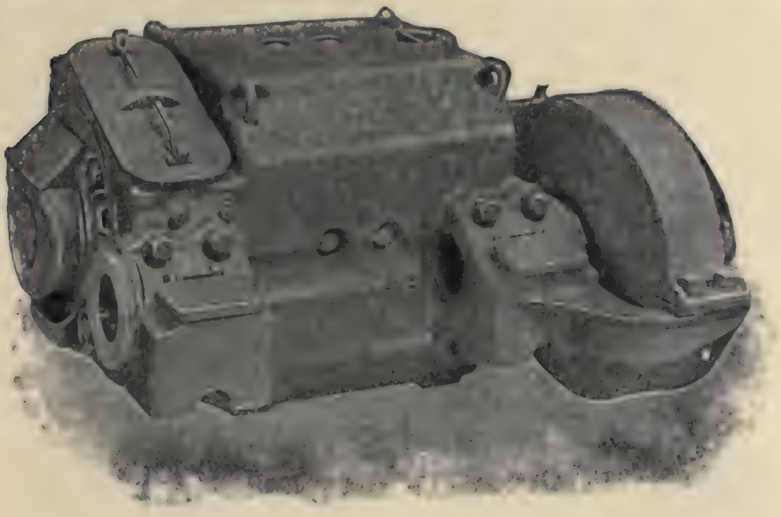

Fig. 89. General Electric Railway Motor.

motors, suitable for elevator service, in capacities from 5 to 45 H. P. In this line, however, the base and pedestals are dispensed with and the bearings are held by brackets bolted to the frame. Their type *C* machine, shown in Fig. 91, gives them sizes from $\frac{1}{4}$ to 10 H. P., to be run on 110-, 220-, or 500-volt circuits. They can be arranged in any position and for any degree of ventilation. They can be built as adjustable-speed motors for a speed variation of 4 to 1 by field weakening. This company also places a number of motors of very small sizes upon the market.

The Reliance Electric & Engineering Co. This concern manufactures the Lincoln direct-current motor shown in Fig. 92. These machines belong to the adjustable-speed class and are built in sizes ranging from ¼ to 30 H. P., and with speed variations as great as ten to one and as small as one desires. It is a simple shunt-wound machine, obtaining its speed variation by altering the magnetic circuit of the machine so as to weaken or strengthen the magnetic field.

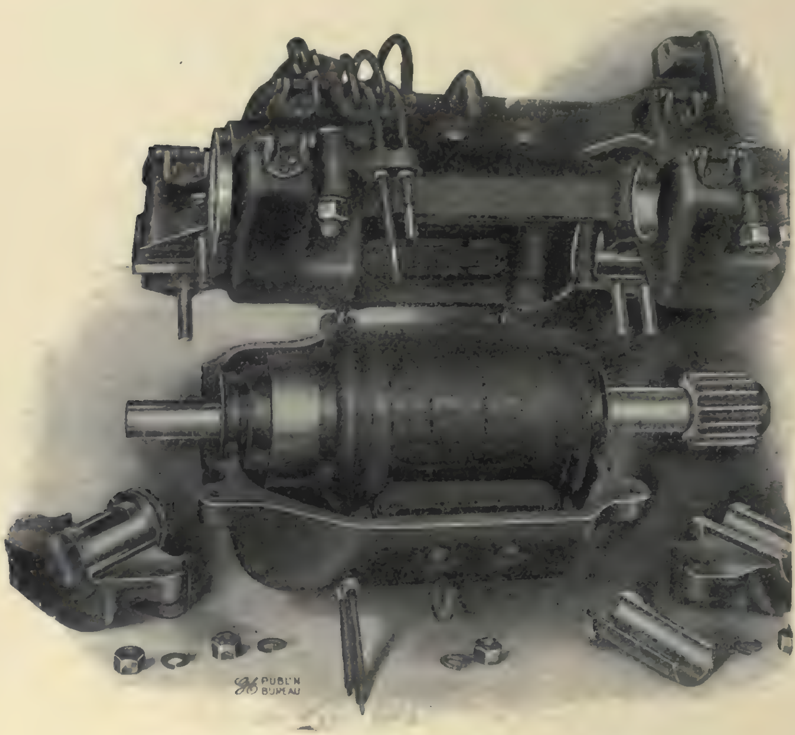

Fig. 90. General Electric Railway Motor Frame Opened.

The principal parts of this machine are shown in detail in Fig. 93, a portion of the illustration being in section. The end of the armature shaft on which the commutator is mounted revolves in a sleeve that slides in the journal bracket. This sleeve is moved back and forth by means of a forked lever controlled through a rod and nut, by the screw on the spindle of the hand wheel. The helical compression spring surrounding the lever rod always balances the

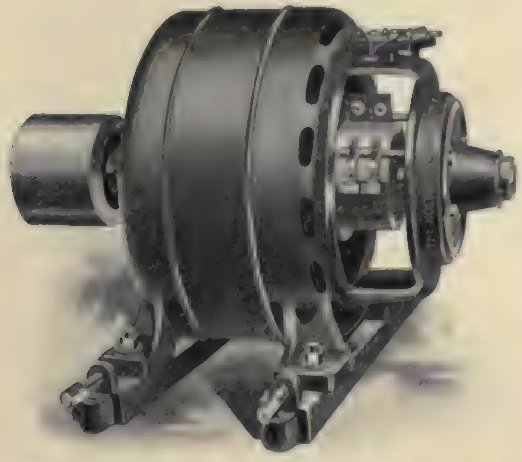

Fig. 91. Holtzer-Cabot Type *C* Direct-Current Motor, Open Type.

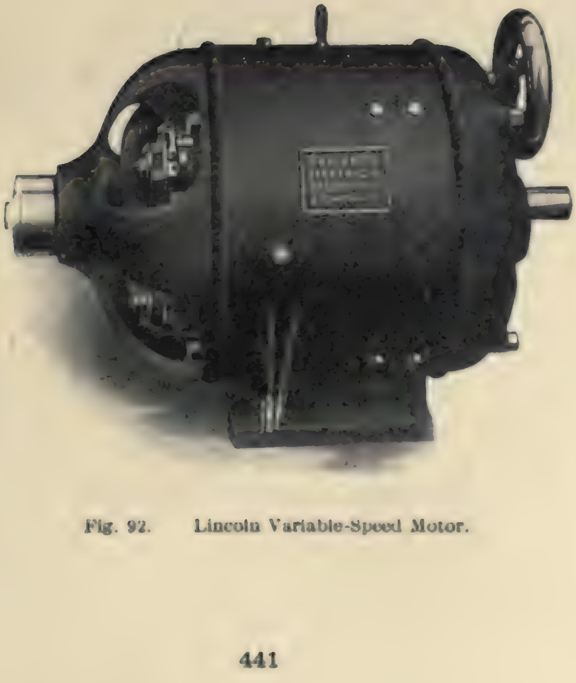

Fig. 92. Lincoln Variable-Speed Motor.

magnetic pull that is exerted by the poles on the armature core. The armature core is slighty tapered, the commutator end being larger in diameter than the other end and the pole faces are bored to the same taper. When the armature is drawn towards the journal bracket on the commutator end, the air gaps are increased in length and decreased in area. This increases the reluctance, thereby weakening the field and thus increasing the speed.

Sparking at the brushes when operating at weak fields is prevented by means of special commutating poles midway between the main poles. These commutating poles are in series connection with the armature and laterally displaced from the main poles on the side toward which the armature is withdrawn. The machine is so designed as to give sparkless commutation at all loads at any speed in either direction. The brush rigging is mounted on the end of the sleeve containing the ball bearing and therefore this bearing, brush rigging, and armature move in unison with no lateral displacement of the brushes on the commutator. The driving end of the shaft slides in a sleeve that revolves with it but does not slide

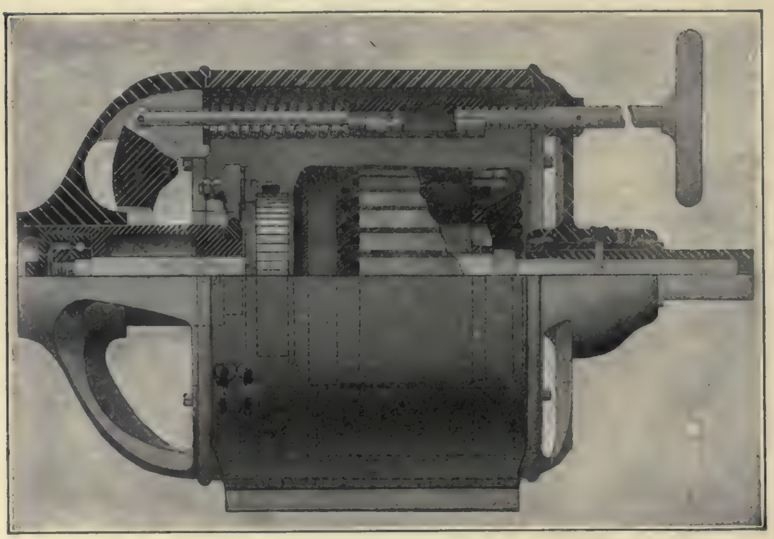

Fig. 93. Cross-Section of Lincoln Motor.

endwise; the driving gear, coupling, or pulley is mounted on the end of this sleeve.

Northern Electric Manufacturing Co. For constant-speed motors this concern employs the frames of their belted-type generators shown in Fig. 49, their ratings then being from ½ H. P. at 900 R. P. M. to 75 H. P. at 800 R. P. M. These machines are furnished for any style of mounting, any degree of enclosure, with back gearing or idler pulleys with spring tension. Series wound, they become varying-speed motors, while with additional regulating or interpoles they become adjustable-speed motors with a speed variation of 4 to 1. Another line of motors manufactured by this company is their type *S*, built up to 50 H. P. constant speed and also a wide range of adjustable-speed ratings with speed variations up to six to one and even greater if desired. The magnetic circuits in these machines are made of laminations, as shown in Fig. 94. The pole piece really consists of two independent magnetic paths, separated by an air gap between them. This prevents field distortion due to armature reaction and allows wide speed variation with sparkless commutation by simple field weakening. Fig. 95 shows diagrammatically the magnetic

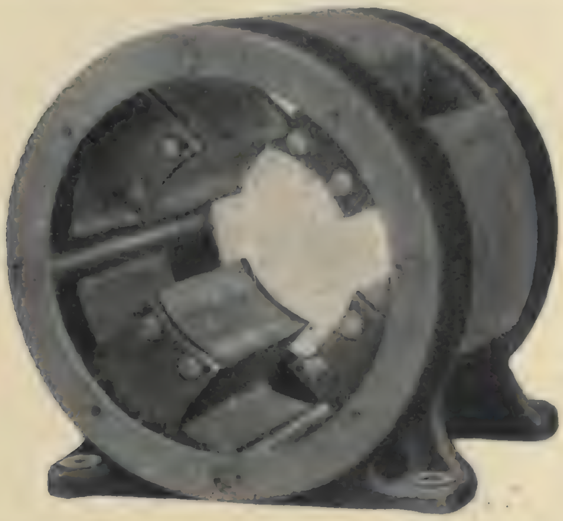

Fig. 94. Northern Type *S* Field, Showing Laminated Structure Secured between Two Cast End Plates. Holes in Casting Near Pole Tips Receive Pins to Secure Field Coils in Place.

circuit from pole to pole. Although each pole is in two halves, the magnetic circuit in each quarter is complete without joints. They

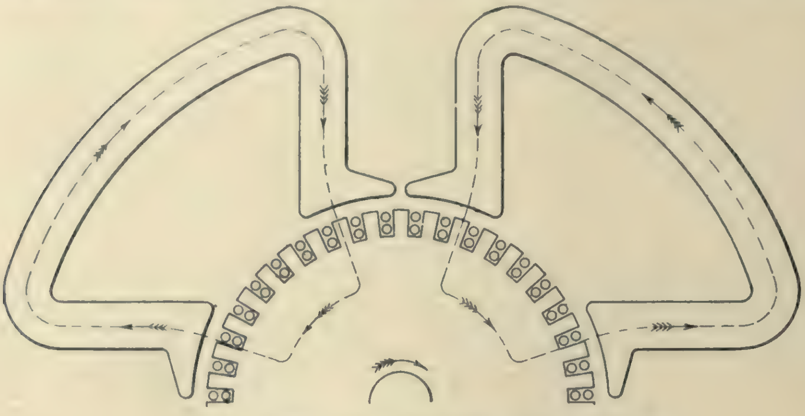

Fig. 95. Magnetic Circuit of Northern Type *S* Motor.

also manufacture a line of crane motors, as shown in Fig. 96. These are rectangular, dust proof, cast-steel frames, 4 pole, and series wound.

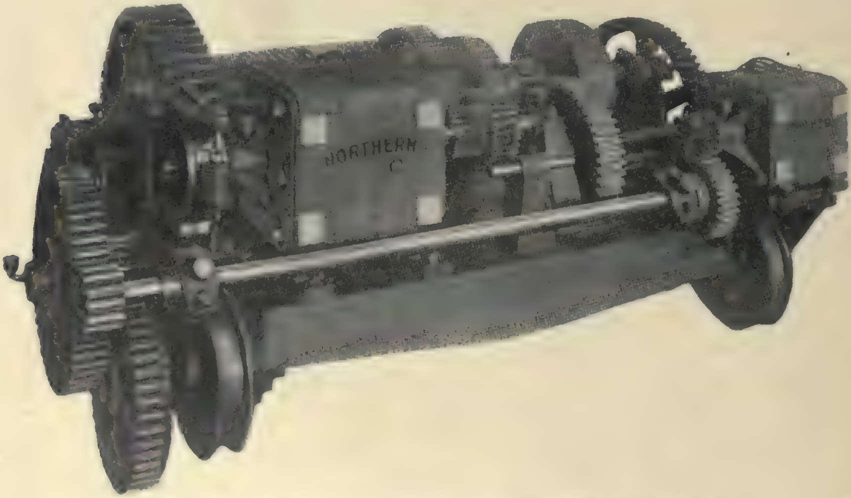

Fig. 96. Crane Trolley as Equipped with Northern Steel Crane Motors.

Sprague Electric Company. The shunt-wound, constant-speed motors placed upon the market by this firm consist of two separate lines. Their round type motors are bipolar and built in frames of

12 sizes, ranging from $\frac{1}{20}$ to $7\frac{1}{2}$ H. P. Fig. 97 shows one of these motors belted to a Whitlock press. The features of these machines are an almost spherical field casting or yoke and only a single field coil to energize both poles. Fig. 98 is a section of such a machine and clearly shows the principal parts. Their other line of motors, illustrated in Fig. 99, is multipolar, manufactured in nine different sizes of frames, the smallest two being 4 pole and the rest 6. They are rated from 10 to 95 H. P. in slow speeds, and 15 to 105, in moderate speeds. They can be furnished for mounting in any of the four usual positions, and with any grade of protection. Both these lines are for use on 115-, 230-, or 500-volt circuits, and when desired can be furnished with series or compound windings, thus becoming varying- or adjustable-speed motors. The Sprague Company also manufactures several sizes and forms of direct-current fan motors.

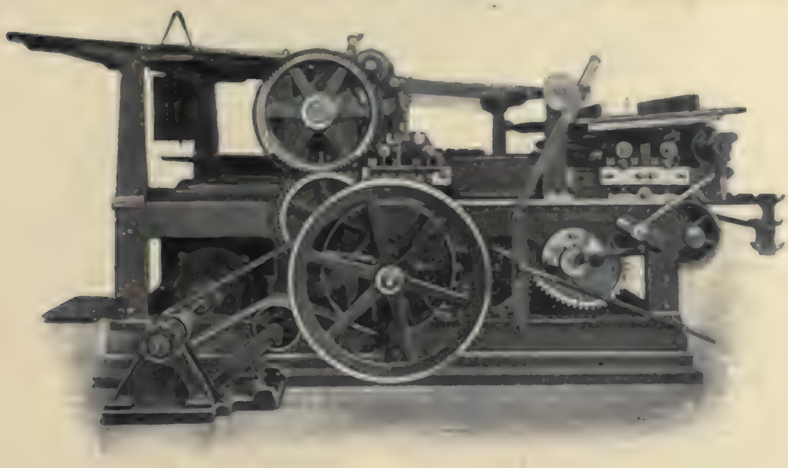

Fig. 97. Sprague Round Type Motor Belted to Whitlock Press.

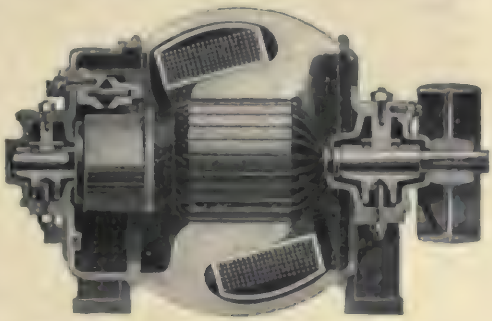

Fig. 98. Sectional View of Sprague Round Type Motor.

Stow Manufacturing Company. The Stow *multi-speed motor,* as it is called, really belongs to the adjustable-speed class, obtaining its speed variations by changing the reluctances of the magnetic circuits. It is bipolar in sizes from ¼ to 4 H. P. and 4 pole from 4 to 15 H. P. Fig. 100 shows one of the 4-pole type. The pole cores are made hollow and provided with iron or steel plungers, the position of which is adjustable through pinions and worm gears operated by a large hand wheel placed on the top or the side of the machine as preferred. When the plungers are withdrawn, the total flux decreases because of the lengthening, and the decrease in the effective area, of the air gap and also the decrease of effective metal in the field cores. The speed must necessarily increase with decrease of flux. Also, when the plungers are withdrawn, the flux is along the polar edges, thus maintaining a strong commutation field and also decreasing armature reaction by increasing the reluctance of the armature flux. These effects allow sparkless commutation at any load at any speed within the limits of the design. These motors can be designed to give a speed variation of 3 to 1.

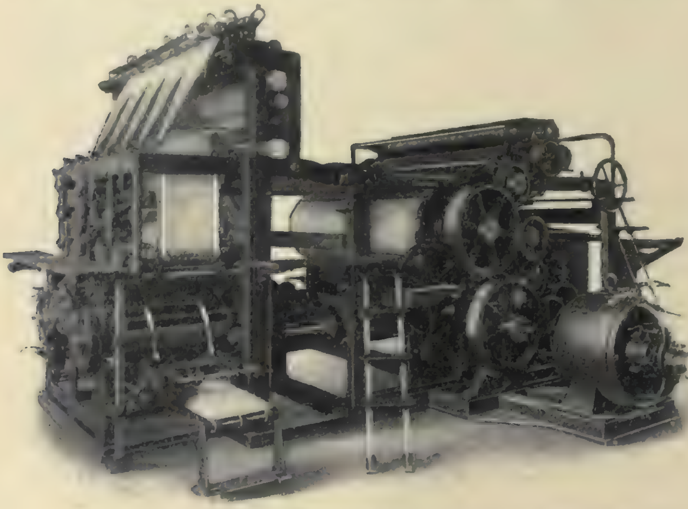

Fig. 99. Sprague Multipolar Motor Connected to Rotary Press.

B. F. Sturtevant Company. This concern places two lines of motors on the market. Their 8-pole motors are made in sizes from 9 to 225 H. P. Those above 40 H. P. are the same in appearance as their generators shown in Fig. 54. The smaller sizes employ 3-arm bearing brackets. Their 4-pole motors are built in 19 sizes of frames from 1 to 100 H. P. and their external appearance is as in Fig. 101. These are all constant-speed machines.

Triumph Electric Company. For their larger sizes in constant-speed machines this company, like the others, employs their belt-driven generator frames of the design shown in Fig. 59. These give rise to a line of motors ranging from 3½ H. P., 4 pole, 1,200 R. P. M., to 200 H. P., 6 pole, 500 R. P. M. They also build a line of steel frame machines of the 2-arm bracket type that can be mounted in any position and has any variety of protection. Six frames are bipolar from ½ to 5 H. P. and 8 frames are 4 pole from 7½ to 40 H. P. They can be wound shunt, series, and compound, thus becoming besides constant-speed motors also varying- and adjustable-speed

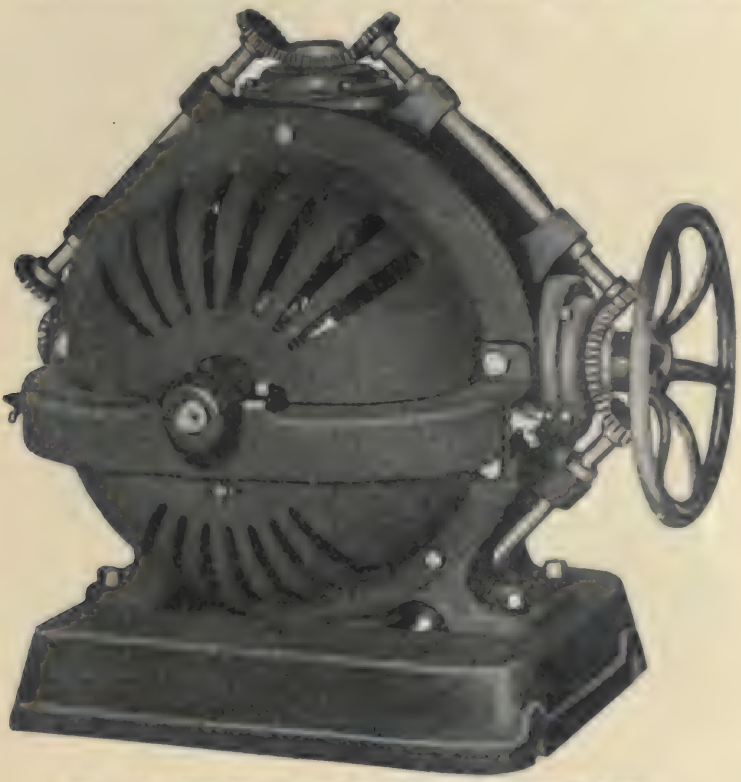

Fig. 100. 4-Pole Stow Motor Multi-Speed, Semi-Enclosed Type.

motors. An illustration of this type of motor is given in Fig. 102. These machines are also used for belted generators from ½ to 35 K. W.

Western Electric Company. Constant-speed motors from ⅝ to 60 H. P. for all voltages and great varieties of speeds are manufactured by this company, using the same frames as their belted generators shown in Fig. 61. They are built for all mountings and the various grades of protection. Fig. 103 shows one of these motors driving a band saw. Another line of motors from ½ to 5 H. P. at speeds from 2,600 to 1,100 for the three standard voltages gives the

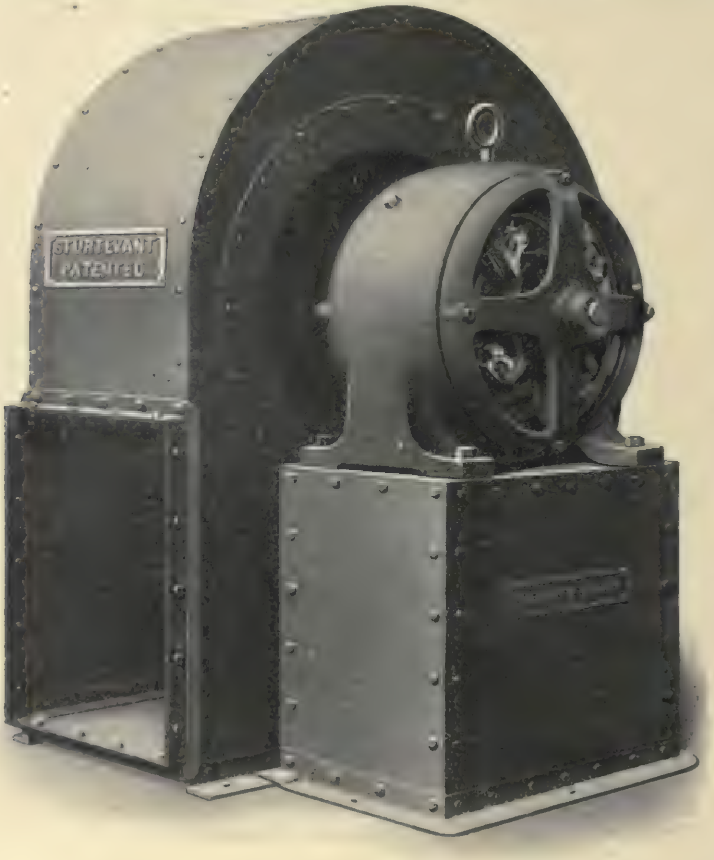

Fig. 101. Sturtevant Electric Fan 4-Pole Motor.

smaller sizes. They are bipolar with a circular yoke. The poles are of a peculiar shape, circular in cross-section where the field coil is, but present rectangular pole faces to the armature. Fig. 104 is a section of this type and shows the construction. They also manufacture 4-pole, series-wound, hoisting motors with totally enclosed frame, small power motors, grinders, and several forms and sizes of fan motors.

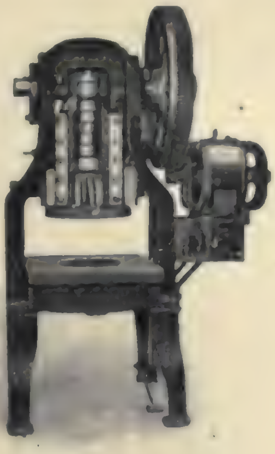

Fig. 102. Triumph Motor Driving a Punch.

Westinghouse Electric & Manufacturing Co. A line of motors, designated type *EM*, are built in standard capacities from 90 H. P. up and for standard voltages from 110 to 650. They are intended to supply the demand for large power units. They are designed for direct connection or to be belted, geared, or coupled to the work. With proper windings they are suitable for constant-, varying-, and adjustable-speed service. They are essentially the same frames as the self-contained generators previously described. One of these motors is shown in Fig. 105. Their line of type *S* motors are made in 13 frames; the

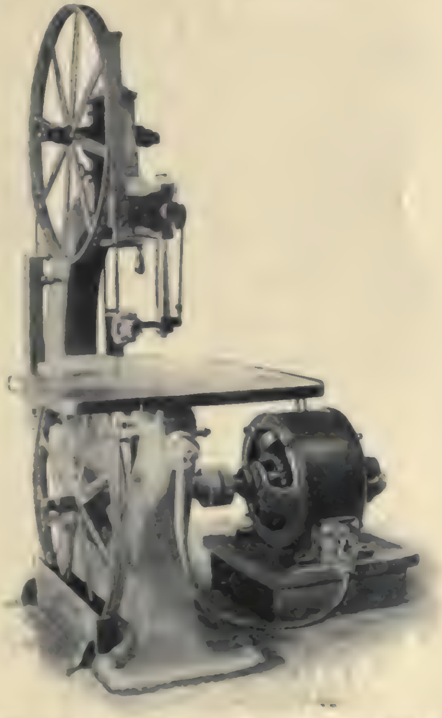

Fig. 103 Western Electric Motor Driving Band Saw.

same as used for the generators of their generating sets shown in Fig., 65. Used as constant-speed motors they have ratings from 2 to 75 H. P. at 110 volts, from 2 to 150 H. P. at 220 and 500 volts, and from 6 to 100 H. P. at 600 volts. They are mounted in any of the four positions and built partially or totally enclosed. One of these machines operating a heavy shears is shown in Fig. 106. They can also be used as adjustable-speed motors for speed variations of 1 to $1\frac{1}{2}$ or 1 to 2. They are also used as elevator motors when furnished with a series winding used for starting but cut out for normal running. Adding auxiliary or interpoles to these shunt-wound machines gives adjustable-speed motors of greater speed variation, of $\frac{1}{2}$ to 23 H. P. at a speed ratio of 1 to 4, $\frac{1}{2}$ to 50 H. P. at a speed ratio of 1 to 3, and another line of elevator motors of 10 to 50 H. P. at a speed ratio of 1 to 2. For the smaller size constant-speed motors they use the 8 frames of their type *R* generators, shown in Fig. 66. The bipolar range from $\frac{1}{6}$ to $1\frac{3}{4}$ H. P. and the 4 pole, from 2 to 10 H. P. These machines are also mounted and enclosed as desired. Similar construction to the bipolar type *R* machines are their fan motors and very small power motors in $\frac{1}{20}$, $\frac{1}{12}$, or $\frac{1}{8}$ H. P. The Westinghouse also furnishes a complete line of railway motors and lines of mill and hoisting motors. Their railway

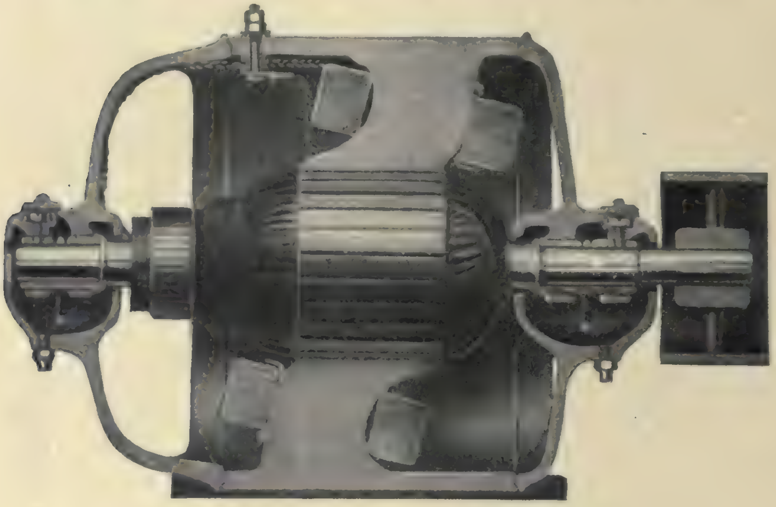

Fig. 104. Section of Western Electric Bipolar Motor.

motors are built with the usual moisture- and dust-proof cast-steel frames. They are 4 pole and series wound for 500 to 600 volts.

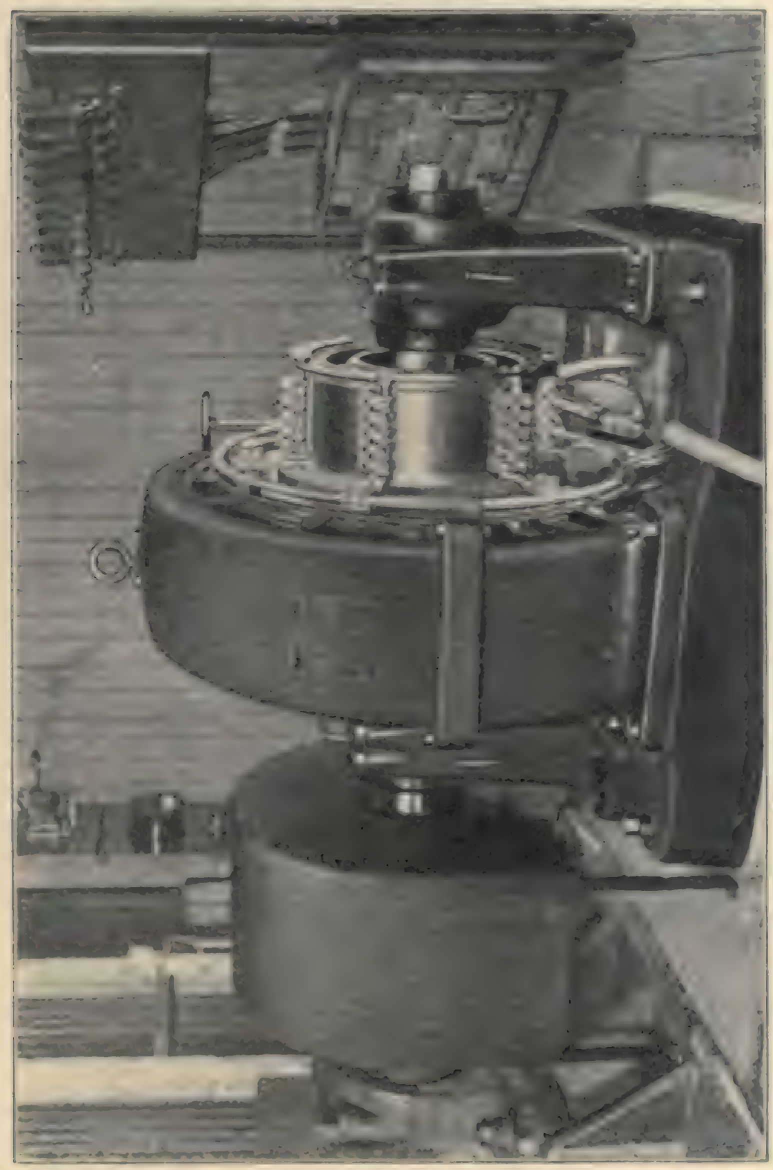

Fig. 105 Westinghouse Dust-Proof Motor Operating Gun Lathe.

One of the latest types is shown in Fig. 107. Their mill motors are of very similar design in five sizes from 25 to 150 H. P., but wound

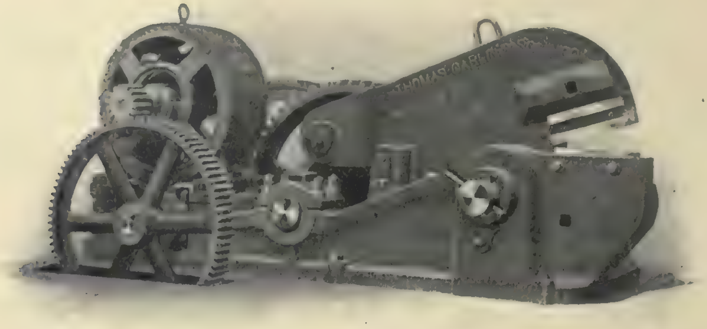

Fig. 106. Westinghouse Type *S* Motor Geared to Carlin's Heavy Shears.

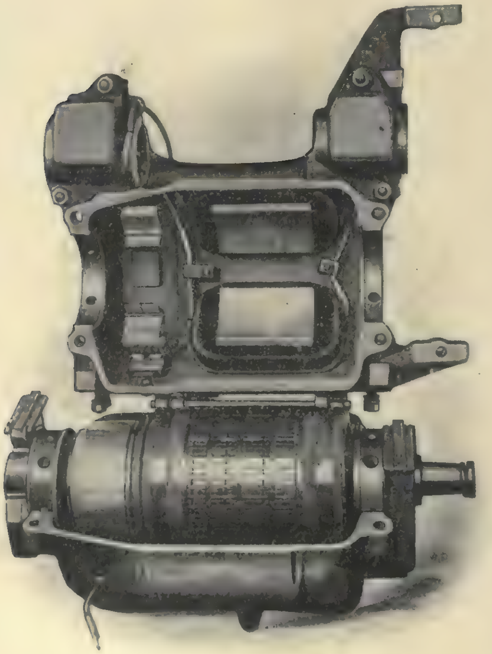

Fig. 107. Westinghouse Railway Motor—Upper Part of Frame Raised.

for 220 volts. They are series or compound wound as desired; in the latter the shunt winding keeps the no-load speed down to about twice full-load speed. Their hoisting motors consist of 10 frames, wound for 110, 220, or 500 volts, ranging from 2 to 52 H. P. They are 4 pole, series wound, fully enclosed. Fig. 108 shows one of these arranged with back shaft and gear.

DYNAMOTORS, MOTOR-GENERATORS, BOOSTERS

Dynamotors. This class of machines has certain advantages resulting from both generator and motor windings being on the same core. The armature reactions of the two windings, being opposite, neutralize each other. There is, therefore, no shifting of the brushes required and no tendency to spark with varying loads, giving them the ability to stand heavier overloads. They are slightly more efficient than motor-generators since energy is saved in magnetizing the fields and there is less loss in the bearings because all torque strain upon the shaft is eliminated. They are also cheaper, of less weight, and more compact. On the other hand, the voltage of the generator cannot be varied to any extent except by introducing ohmic resistance into either generator or motor armature circuits. Also the generator voltage cannot be maintained absolutely constant as there is no way of correcting for the armature drop. They are used principally in place of batteries in telegraph main stations, for charging storage batteries in central energy telephone

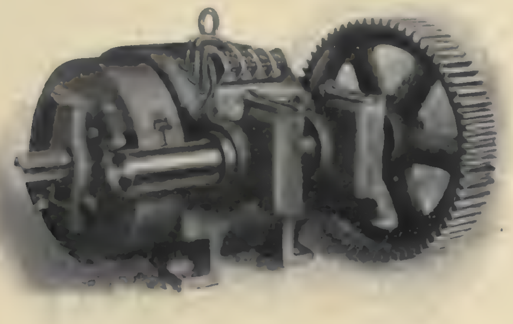

Fig. 108. Westinghouse Hoisting Motor with Back Shaft and Gear.

stations, and for electro-cautery and electroplating work. This type of machine is only made in the smaller sizes, the output rarely being as high as one kilowatt. The motor winding is arranged for any of the standard voltages and the generator winding delivers from 6 or 8 to 30 or 40 or else from 100 to 600 volts, depending upon their special use. Fig. 109 shows a Crocker-Wheeler dynamotor. There is a variety of dynamotors where the generator winding furnishes alternating current through collector rings. This type is largely used by many companies for ringing telephone bells.

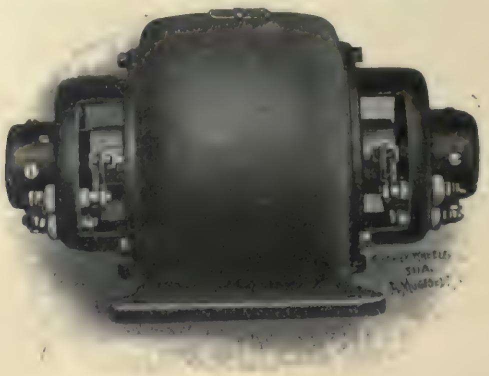

Fig. 109. Crocker-Wheeler Dynamotor.

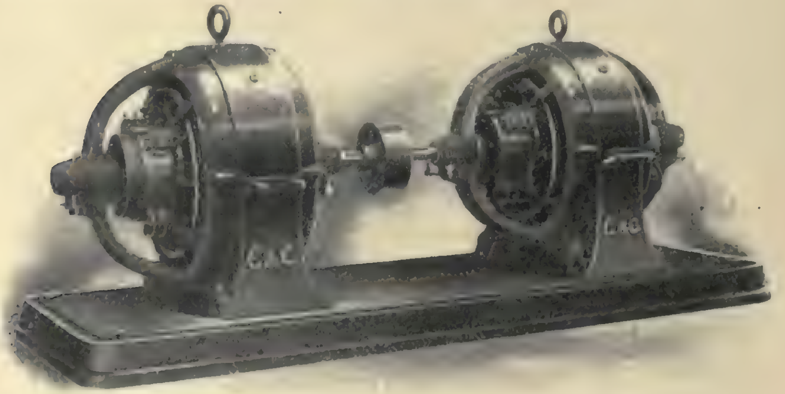

Fig. 110. C & C Type *SL* Welding Set.

Motor-Generators. Being any combination of standard machines, motor-generators come in almost any capacity. They find their most general application in transforming from alternating to direct current and the reverse. That is, one of the machines is direct current and the other is alternating. It is only in the smaller sizes and special applications that both machines are direct current.

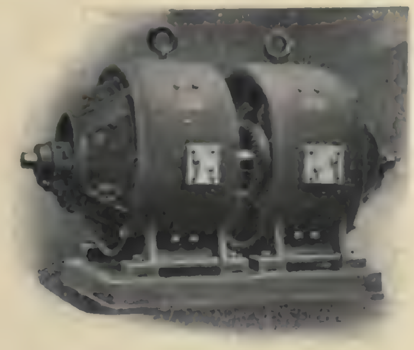

Fig. 111 Westinghouse Motor-Generator.
Type *S* Generator Driven by Type *S* Motor with Two Bearings
and Continuous Shaft.

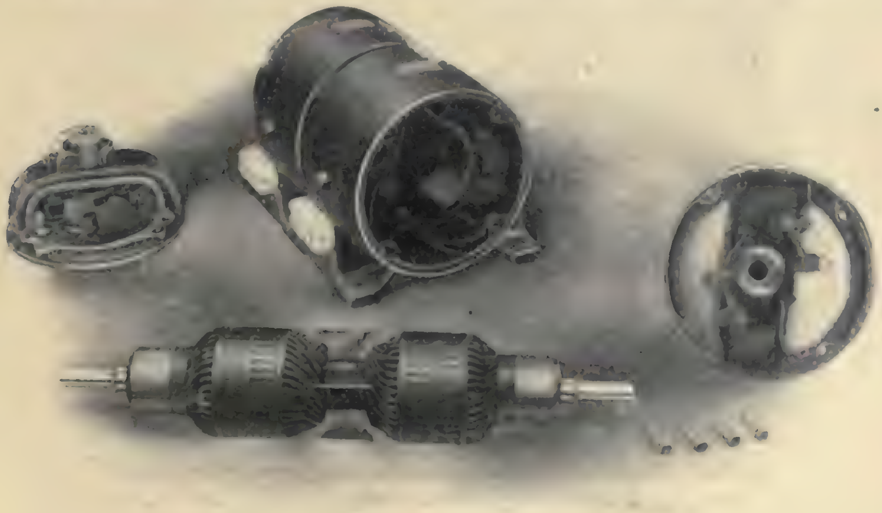

Fig. 112. View of Disassembled General Electric Balancer Set

A special adaptation is illustrated in Fig. 110, which shows a C & C type *SL* welding set. The two machines are merely coupled together and bolted to a common bed plate. In the smaller sizes the set is very often arranged with continuous shaft and only two bearings. Fig. 111 shows two type *S* Westinghouse machines so arranged. Motor-generators having both machines direct current and of the same voltage find their greatest application in connection with the three-wire system for furnishing the neutral point for connection to the neutral wire, the two outside wires being fed from a single two-wire generator. The two armatures are connected in series between the outside mains and the common point between the two armatures is connected to the neutral. Thus arranged the set is also termed a *balancer*, a *balancer set*, or a *compensator*. An adaptation of this kind of the smaller line of belted generators gotten out by the General Electric Company is shown in Fig. 112. Since the sets are somewhat enclosed in the middle, a fan is provided and mounted between the armatures. For various systems of multiple voltage motor control, the two armatures may be of different voltages. A three-wire Bullock balancer is shown in Fig. 113. In connection with four-wire systems the set is composed of three machines.

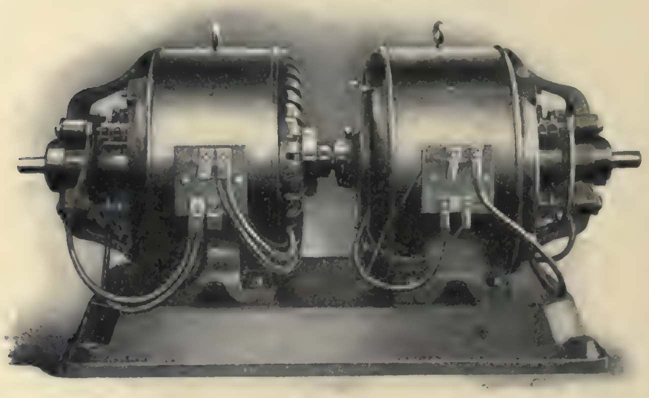

Fig. 113. Three-Wire Balancer for Bullock Multiple Voltage System.

Boosters. These machines are employed for purposes of voltage regulation in connection with direct-current electric lighting, power, and railway circuits, and with storage battery applications. The voltage of these circuits falls off, at points distant from the station, considerably with increase of load, and the booster is connected with the circuits in such a way that its voltage is added to that of the circuit, keeping the voltage constant. In nearly all cases they are motor driven, the motor being a shunt-wound machine and the generator a series- or compound-wound type. Fig. 114 shows a railway booster of Westinghouse manufacture composed of a series generator and a shunt motor.

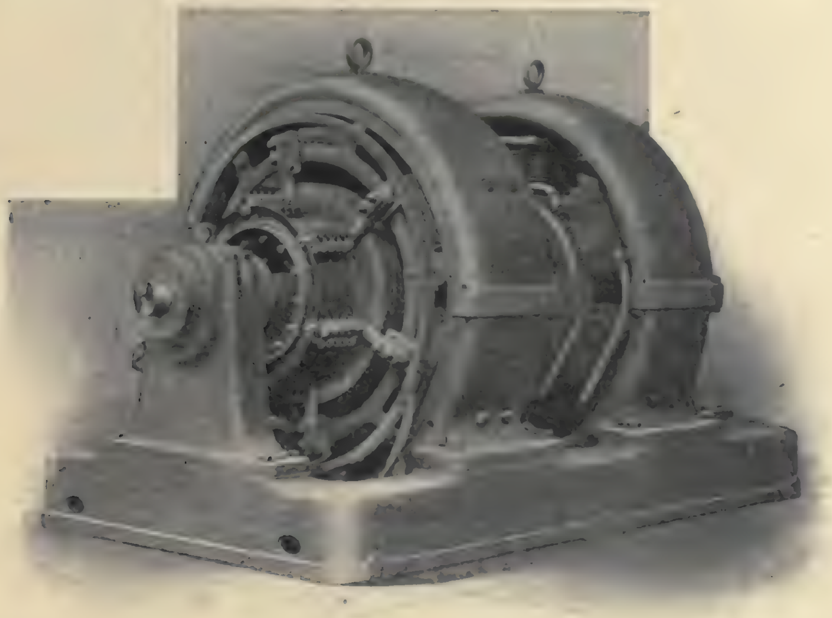

Fig. 114. Westinghouse Railway Booster, Motor Driven.
250-K. W., 250-Volt D. C. Series Generator—365-H. P., 550-Volt Shunt-Wound Motor.

REVIEW QUESTIONS.

PRACTICAL TEST QUESTIONS.

In the foregoing sections of this Cyclopedia numerous illustrative examples are worked out in detail in order to show the application of the various methods and principles. Accompanying these are examples for practice which will aid the reader in fixing the principles in mind.

In the following pages are given a large number of test questions and problems which afford a valuable means of testing the reader's knowledge of the subjects treated. They will be found excellent practice for those preparing for Civil Service Examinations. In some cases numerical answers are given as a further aid in this work.

REVIEW QUESTIONS

ON THE SUBJECT OF

ELECTRICAL MEASUREMENTS

---

1. What is the distinction to be made between fundamental and derived units? Give examples of each.

2. Describe briefly the different types of galvanometers and explain wherein they differ and the advantages of each.

3. Voltmeters and ammeters are really *galvanometers*. Why do they fall into this class and to which type do they belong?

4. Explain the *lamp and scale* and the *telescope and scale* methods of reading galvanometer deflections.

5. Describe the control magnet as used with needle galvanometers and explain its function.

6. Describe and explain the electrodynamometer and the wattmeter. How do they differ?

7. Describe the rheostat. What materials may be used for the resistance?

8. How do resistance coils differ from the rheostat mentioned in Question 6? What material is generally used for accurate resistance units and why?

9. Describe and explain the use of shunts for galvanometers.

10. Explain the Wheatstone's bridge. Describe the two usual forms of the bridge.

11. Make the usual "diamond" diagram of the connections of a bridge and find the value of X when $M = 1{,}000$, $N = 10$, and $P = 3{,}247$.

12. Describe a good method for measurement of a low resistance.

REVIEW QUESTIONS

ON THE SUBJECT OF

ELECTRIC LIGHTING

---

1. Define what is ordinarily meant by the term *efficiency of an incandescent lamp*, and give the values accepted at present for the efficiency of the carbon, gem, tantalum, and tungsten types.

2. What are the essential features of the Nernst lamp? Why is the ballast necessary?

3. What use is made of the flicker photometer?

4. How may the color of the flaming arc lamp be changed? With what color of light is the efficiency of this lamp the highest?

5. What is the object of shades and reflectors?

6. Describe the globe photometer and give its use.

7. What is the relation between the *hefner* and the *candle-power?*

8. What do you understand by the term *indirect lighting?*

9. Give your understanding of the Rousseau diagram and its use.

10. Name the advantages and disadvantages of the mercury vapor lamp and outline the two methods used in starting this type of lamp.

11. Explain the terms *mean spherical candle-power; mean hemispherical candle-power; mean horizontal candle-power.*

12. Define a *lumen;* a *foot-candle.*

13. In what way does the treatment of the filament of the gem lamp differ from that of the ordinary carbon filament?

14. Why are enclosed arc lamps preferable to open arcs? What is the approximate difference in the voltage at the terminals of these two types of lamps when connected in series circuits?

15. What use is made of the mercury arc rectifier in connection with lighting?

REVIEW QUESTIONS

ON THE SUBJECT OF

ELECTRIC RAILWAYS

PART I.

---

1. (*a*) Upon what does the heat developed in an electric heater depend? (*b*) Explain the method of obtaining different degrees of heat in the electric car. (*c*) How much power in K. W. is consumed in heating a car, if the heaters take 6 amperes and the cars run on a 500-volt circuit?

2. (*a*) State briefly the essential requisites for a first-class car motor. (*b*) Describe one form of motor suspension.

3. What is the speed, in revolutions per minute, of the motor armature of a car going at the rate of 8 miles per hour? Diameter of car wheel = 33 inches, single reduction gear, 14 teeth on the pinion, 72 on the axle gear.

4. Explain the series-parallel method of controlling the speed of a car, and the method of gradually increasing the speed of a car by the General Electric K type controller.

5. Give the principle of a good form of electric brake.

6. What is meant by the "Multiple Unit Control" system?

7. In the K controller how is arcing prevented between the contact rings and fingers, when the circuit is broken?

8. What forms of resistance are commonly used in electric railway work?

9. What is the "dead man's handle"?

10. What is the canopy switch and in what way is the car circuit-breaker superior to it?

11. Explain the action of the air brake.

12. Which is used more frequently the Westinghouse automatic air brake, or the straight air brake in electric railway work?

REVIEW QUESTIONS

ON THE SUBJECT OF

ELECTRIC RAILWAYS

PART II.

---

1. Draw a diagram showing the course of the current in the return circuit when the rail is paralleled by a large water main. Denote the points at which the strongest electrolytic action will take place on the pipe, assuming the trolley positive.

2. What are the advantages of the third-rail system?

3. What are the most important factors to be considered in locating a power house for a given system?

4. How may the alternating current be applied to electric railway work, direct-current motors being used on the cars?

5. (*a*) How is the electrical circuit maintained at switches and crossings in the third-rail system? (*b*) How is the car enabled to cross such places?

6. Give the principle of the automatic circuit-breaker.

7. Why is it necessary to bond the rails?

8. Explain how and for what purpose storage batteries can be used in railway plants.

9. Why is it necessary to use feeders on long lines?

10. Explain why pipes in the vicinity of the power house should be connected electrically to the negative terminal of the generator when the trolley is positive.

11. In testing rail bonds, the bond and one foot of the rail over it should have a resistance of how many feet of solid track?

12. Describe briefly the conduit system. In what cities is it used?

REVIEW QUESTIONS

ON THE SUBJECT OF

TYPES OF DYNAMO-ELECTRIC MACHINERY

1. Define or explain *dynamo-electric machinery.* Name the main divisions of this kind of machinery.

2. What are the principal ways of driving generators?

3. Explain briefly the three different arrangements of generator and steam engine which result in a direct-driven unit.

4. What is a three-bearing generator? Why is it so constructed and about what is the smallest K. W. capacity of this type?

5. State briefly the objections to belting generators to steam turbines.

6. In what instances is gearing used between the generator and the prime mover?

7. About how many K. W. will the largest direct-current generator furnish when built in the engine type; how many when belted?

8. What are the advantages and disadvantages of direct-driven generators as compared with belt-driven?

9. Into what classes are constant-voltage, direct-current generators divided and to what uses are they put?

10. What is meant by a generator being over-compounded ten per cent?

11. Explain what is meant by an *ironclad armature.* How are the armature windings held in place in this construction?

12. What advantages result from bolted-in poles? from cast-welded poles?

13. Explain what is meant by a *ventilated armature* and describe the method of construction.

14. Mention the special features of the DeLaval generating units.

15. What offices do pole shoes or pole horns fulfill?

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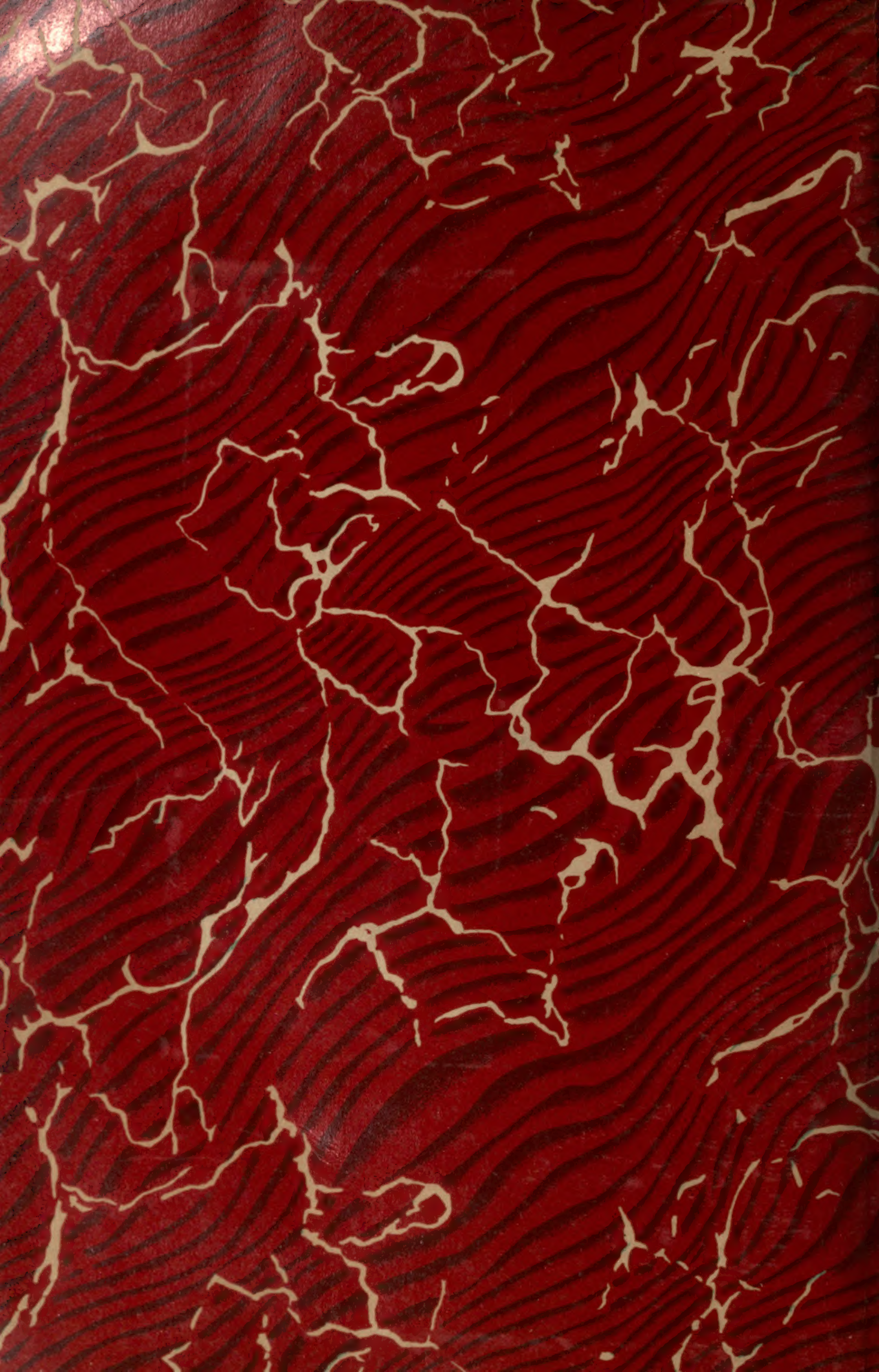

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